Digital technologies as support for learning about the marine environment

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Digital technologies as support for learning about the marine environment

Steps toward ocean literacy

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Abstract

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Over the last century the ocean has been negatively impacted by human activities. In order to continue benefitting from marine services and goods, and the qualities afforded to human life through the ocean, citizens need to be informed about their relationship to the ocean and their own impact on it, that is they need to be ocean literate. Marine education is challenging, as most of the ocean is invisible to the human eye and marine processes are spread over large temporal and spatial scales. Digital technologies have the potential to support learning about the ocean as, virtually, they can take learners into the depths of the ocean and help them visualise complex interactions between different factors over time and space. This thesis consists of four studies scrutinising the role of different digital technologies for learning about marine environmental issues with an emphasis on communicative aspects, with two of the studies having a specific focus on ocean literacy. Study I is a literature review of the use of digital technologies in environmental education. Study II investigates the use of a marine research institute's Facebook page aimed at supporting communication and learning about marine topics. Study III addresses the use of a carbon footprint calculator as an opportunity for students to reason about their greenhouse gas emissions. Finally, Study IV analyses the questions asked by students on an online platform where they engage in an asynchronous discussion with a scientist around the issues of ocean acidification. The four studies show how the use of digital technologies in environmental education can make the invisible visible, allowing engagement with and manipulation of the abstract features of the ocean. As

demonstrated in my studies and as is evident from previous research in the multidisciplinary field of environmental science, digital technologies offer new means to make sense of and engage with global environmental issues. These technologies provide a field of action where users can experiment, make mistakes, get feedback and try again in ways that are different from paper-based learning activities.

The findings from Studies II, III and IV also illustrate the challenges associated with these technologies, and it becomes obvious that the technical features of a tool do not determine the kind of interactions that will evolve from its use. The contexts in which a tool is used, and what the features mean to the users in situ, are key, and demonstrate the importance of studying not only the outcome of a learning practice but also the ongoing interaction between the users and the tool in a specific context. In conclusion, this thesis offers an overview of the range of impacts that digital technologies can have on the development of ocean literacy, as well as illustrating how technologies open up new ways of learning about marine environmental issues both inside and outside of school. It also provides an account of why ocean literacy is such an important skill for 21st-century citizens living in a rapidly changing world with significant challenges to the environment and our own habitats.

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The four articles of this thesis are reprinted with permission from the publishers: Taylor & Francis Online, Elsevier, and Sense Publishers.

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Study II: Fauville, G., Dupont, S., von Thun, S., & Lundin, S. (2015). Can Facebook be used to increase scientific literacy? A case study of the Monterey Bay Aquarium Research Institute Facebook page and ocean literacy. *Computers & Education, 82,* 60–73.

Study III: Fauville, G., Lantz-Andersson, A., Mäkitalo, Å., Dupont, S., & Säljö, R. (2016). The carbon footprint as a mediating tool in students' online reasoning about climate change. In O. Erstad, K. Kumpulainen, Å. Mäkitalo, K. C. Schröder, P. Pruulmann-Vengerfeldt, & T. Jóhannsdóttir (Eds.), *Learning across contexts in the knowledge society* (pp. 39–60). Rotterdam, the Netherlands: Sense Publishers.

Study IV: Fauville, G. (2017). Questions as indicators of ocean literacy: Students' online asynchronous discussion with a marine scientist. *International Journal of Science Education.*

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[1] Warnings such as "You will come to hate your supervisors" – a phase that I diligently prepared for but that, surprisingly, never came.

[2] On top of having sharp minds and giving me thoughtful comments.

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[3] Even if "it ain't real science"! ☺

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Fiskebäckskil, October 2017
Géraldine Fauville

1. Introduction: Living in a changing world

While all the Earth's systems are interconnected and vital for the livelihood of humans, this thesis focuses on environmental issues that impact on the ocean. This focus originates from my background as a marine biologist, my deep interest in the conservation of the ocean through increasing public awareness, and the central role the marine environment plays in the sustainability of our species.

In the context of the intense debates about climate change, the marine environment is often overlooked. The dramatic consequences for the ocean and marine ecosystems of current changes in climate appear much less visible to politicians, the media and the public than what is happening to the terrestrial systems. Nevertheless, a general public awareness of the marine environment needs to be developed for these issues to be addressed in responsible and informed ways that are based on knowledge and understanding of the ocean. In order for citizens to become participants in the debate about marine environmental issues, they need to be ocean literate, that is they need to understand the ocean's influence on them and their influence on the ocean. Elaborating on this understanding of interdependences, Cava, Schoedinger, Strang, and Tuddenham (2005) defined an ocean-literate person as someone who understands the fundamental concepts about the functioning of the ocean, who is able to communicate about the ocean in a meaningful way, and who is able to make informed and responsible decisions regarding the ocean and its resources.

In this respect, it is important to investigate how ocean literacy can be fostered both through informal efforts and activities and through education. This thesis consists of four studies scrutinising the role of different digital technologies for learning about marine environmental issues with an emphasis on communicative aspects, with two of the studies having a specific focus on ocean literacy.

In this chapter, I will briefly describe the environmental context in which citizens live and what this entails in term of knowledge and responsible behaviour in relation to the marine environment. I will discuss a) the concept of ocean literacy, b) the challenges to learning about the ocean and c) the support that digital technologies could offer in the attempts to promote such literacy.

Living in the Anthropocene

The rapid expansion of the human population and the increasing exploitation of the resources of the Earth have been shown to be disruptive for the functioning of the Earth's systems. At the turn of the 21st century, Crutzen (2002) proposed the concept of the Anthropocene to capture the evident shift in the relationship between humans and the global environment. The term Anthropocene is now widely accepted as an informal way of referring to the fact that humankind is responsible for moving the Earth out of its current geological epoch, the Holocene (Steffen, Grinevald, Crutzen, & McNeill, 2011).

The industrial revolution, starting in the late 18th century with the beginning of the exploitation of fossil fuels, is commonly accepted as marking the beginning of the Anthropocene (Crutzen, 2002). The use of fossil fuels allowed humankind to engage in new activities and expand existing ones, which has resulted in significant changes in their livelihood. As a consequence, between 1800 and 2000, the human population grew from approximately one to six billion (and is expected to reach ten billion by the end of this century) (Steffen, Grinevald, Crutzen, & McNeill, 2011). In addition, over the same period, the use of energy increased by forty times and the surface of land used for human activities rose from ten per cent to about thirty per cent. Simultaneously, humans began to increase the conversion of natural ecosystems into cropland and to build more and larger dams, examples of the suddenly increasing anthropogenic impact on the environment (see Steffen et al., 2011 for a detailed history of the modification of human–environment interaction).

The impact of human activity on ecosystems is now difficult to ignore. The most recent report by the World Wide Fund for Nature (2016) points out that "the future of many living organisms in the Anthropocene is uncertain" (p. 12). As detailed in the report, between 1970 and 2012 the biodiversity abundance has decreased by 58 per cent among the population of more than 3,500 vertebrate species. In other words, many species are increasingly affected by unsustainable human activities, which contribute to degradation and habitat loss, overexploitation of natural resources, climate change and pollution. At the same time as the report warns us about the persistent downward trend of biodiversity abundance among populations of vertebrate species, it challenges readers to take on the task of protecting nature while offering an equitable home for every citizen of this finite planet.

Human activities have been affecting the three major Earth systems – land (e.g. through deforestation), ocean (e.g. from overfishing) and atmosphere (e.g. from the ozone hole). Moreover, these systems are so tightly intertwined that the human activities taking place on land will have repercussions in the atmosphere and in the ocean. Currently, one of the main ways in which human activity is disrupting the Earth is through our constantly increasing release of greenhouse gases. Greenhouse gases (such as carbon dioxide, water vapour and methane) are, within a certain volume, essential for life on our planet. By trapping some of the heat in our atmosphere, greenhouse gases set the average temperature of the Earth around 15 degrees Celsius instead of the average -18 degrees Celsius without this greenhouse effect. However, the human activities described above are responsible for worrisome increased greenhouse gases emissions in the atmosphere, leading to a greater greenhouse effect. The trapping of more heat in the atmosphere thus increases the average temperature on Earth and modifies the global climate (this is the focus of Study III). In addition, about a third of the CO_2 emitted by human activities gets dissolved in the ocean and changes the seawater chemistry by making it more acidic, a phenomenon referred to as ocean acidification (focus of Study IV). Since the emissions of CO_2 by human behaviour have so many negative consequences on our planet, it is essential for citizens to be aware of and knowledgeable about how their own behaviours contribute to this global environmental issue and how they can act on the basis of such insights.

Living on a blue planet

The significance of the ocean for human life

The ocean, covering 71 per cent of our planet and constituting 97 per cent of the Earth's water, is a key system, playing several crucial roles that support the livelihood of humans. For example, through photosynthesis of marine phytoplankton, the marine environment supplies roughly 50 per cent of the oxygen we breathe. Fisheries provide about 15 per cent of the total protein consumed across the globe, with a higher percentage in developing countries (World Health Organization, 2012). Some marine ecosystems serve as protection against natural disasters, while others are essential to leisure and tourism or have spiritual, cultural and aesthetic significance for different communities. The Organisation for Economic Co-operation and Development (2016) reports that the economy linked to the ocean can be estimated at 1.5 trillion US dollars and employment in the ocean industry amounts to around 31 million jobs per year. The Earth's climate and weather patterns are regulated by the ocean, which stores an important amount of solar heat and transports it from the equator to the poles. The ocean is also the largest long-term sink for atmospheric CO_2, absorbing about a third of this gas emitted at an increasing pace by human activities since the beginning of the industrial revolution. The ocean is also recognised as a potential reservoir of pharmaceutical products (Glaser & Mayer, 2009).

These examples illustrate how the ocean supports life on Earth and is essential to human well-being. One could argue that all aspects of our life (e.g. cultural, historical, biological and economic) are deeply connected to the ocean, no matter where we live on Earth. Needless to say, the ocean should not be seen solely as a resource for humans but should be valued for its own sake as well as for the sake of its inhabitants.

Degradation of the marine environment

Despite its intrinsic and extrinsic values, the ocean is now showing significant signs of change as a result of human activities. The average temperature of the ocean is increasing while its chemistry is modified by the large amount of CO_2 dissolving in seawater (Pörtner et al., 2014). The majority of the fish stocks used for catch is either fully fished or overfished (Food and Agriculture Organization of the United Nations, 2016). Moreover, the increasing social and economic pressures from the exploding human population have led to important alterations in marine habitats (Rockström et al., 2009) and eutrophication of ecosystems due to agricultural nutrient runoff (Kelly et al., 2011). WWF reported that the marine Living Planet Index (LPI)[4] declined by 44 per cent between 1970 and 2012 (WWF, 2016). To give a concrete

[4] The LPI is a measure of the state of the Earth's biological diversity based on vertebrate species population trends over time. This index draws upon data available concerning the size of the population and tracks the change to these data over time.

example, the fishing of sharks and rays had tripled between 1950 and 2003. Since then, however, the catches have decreased, although not because of improved fishing regulations but as a result of declining populations. About one in four species of rays and sharks is threatened with extinction due to overfishing (Dulvy et al., 2014). The increasing modification, destruction and pollution of the ocean threatens humankind by putting at risk all the services and goods we benefit from and depend upon. As articulated by Earle (1995): "If the sea is sick, we'll feel it. If it dies, we die. Our future and the state of the oceans are one" (p. vii).

Developing ocean literacy

As the degradation of the marine environment has a direct impact on citizens and can be partially attributed to the lifestyle choices made by these citizens, marine issues must be regarded as social issues (Longo & Clark, 2016), and the involvement of each and every one of us in these questions is important. While the conservation and management of the marine environment used to be dealt with through a top-down political and administrative approach, a transition has recently occurred towards more participatory conservation strategies. These strategies focus more on the involvement of citizens, as policies for marine protection should address public behaviour (McKinley & Fletcher, 2010). This shift in the way the marine environment is dealt with is supported at policy levels both in Europe and in the USA, as shown in the reports by the Pew Oceans Commission (2003) and the European Marine Board (2013):

> If we are to succeed in implementing a new national ocean policy to restore and maintain ocean ecosystems, we will need more than new laws and institutions. We must build a national constituency for the oceans that includes all Americans, whether we live along the coast or in the Rocky Mountains. We must prepare today's children to be tomorrow's ocean stewards. (Pew Oceans Commission, 2003, p. 92)

> [P]reparing an entire community for a closer relationship with the sea is rewarding for the marine research community and science policy-makers as a more informed public will better understand and support investments in ocean science and be better aware of the need to sustainably manage vitally important marine ecosystems. (European Marine Board, 2013, p. 179)

As stated earlier, citizens need to be ocean literate in order to participate in the debate about marine environmental issues. They need to understand the ocean's influence on them and their influence on the ocean. Based on these interdependences, Cava, Schoedinger, Strang and Tuddenham (2005) define an ocean literate person as someone a) who understands the fundamental concepts about the functioning of the ocean, b) who is able to communicate about the ocean in a meaningful way and c) who is able to make informed and responsible decisions regarding the ocean and its resources.

Challenges and opportunities for marine education

Marine science education is an essential means of promoting ocean literacy, but it encounters a series of challenges that need to be overcome. While some of these challenges will be discussed further in the following chapters, I will present an overview here to set the stage. The ocean consists of a wide range of physical, biological, chemical and ecological processes that occur over different time and space scales. This makes it difficult for people to understand the numerous interactions taking place in the ocean and to comprehend how a disruption here could have repercussions across time and space. Also, the school systems present a terrestrial bias in their science curricula, leading to a situation where younger generations are more equipped to comprehend terrestrial than marine environmental issues. Finally, first-hand experience of the marine environment can be difficult for many because the ocean is often not on our doorstep in the way the terrestrial environment is.. Even when people do live by the coast and are able to connect regularly with the ocean, most of its ecosystem is hidden under the surface or kilometres away from the coast.

Digital technologies have the potential to overcome these challenges to some extent by, virtually, bringing humans and the ocean closer and by making some of the complex interactions visible to the human eye.

General aim and outline of the thesis

The overarching aim of my thesis, grounded in a sociocultural perspective on learning, is to contribute to our knowledge of how digital technologies can support learning and communication in the context of environmental education and, especially, how such resources may promote ocean literacy.

The thesis consists of two main sections, the first of which is made up of the following chapters:

- Chapter 2 gives an overview of the international research concerning the state of ocean literacy among citizens. As the ocean is remote by nature and complex to understand, this chapter also provides a brief literature review discussing how to overcome these challenges.
- In Chapter 3, I discuss how technologies have become ubiquitous in our life and what implications this has for learning. I also review some of the literature that will inform each of the four studies of this thesis. Finally, I reflect on the tensions and challenges arising from learning about the ocean through digital technologies or through first-hand experience of the natural world.
- Chapter 4 presents some of the premises of the sociocultural perspectives on learning relevant to my studies. The significant role played by language in learning is also discussed.
- Chapter 5 presents the research questions based on the theoretical framework and the literature review.
- In Chapter 6, I describe the different approaches that have been taken to analyse the empirical materials of the four studies.
- Chapter 7 provides summaries of each of the four studies included in the thesis.
- Chapter 8 is a discussion of my findings.
- Chapters 9 and 10, respectively, are extensive summaries in Swedish and French.

The second section includes the following four studies:

- Fauville, G., Lantz-Andersson, A., & Säljö, R. (2013). ICT tools in environmental education: Reviewing two newcomers to schools. *Environmental Education Research, 20*(2), 248–283.
- Fauville, G., Dupont, S., von Thun, S., & Lundin, S. (2015). Can Facebook be used to increase scientific literacy? A case study of the Monterey Bay Aquarium Research Institute Facebook page and ocean literacy. *Computers & Education, 82*, 60–73.
- Fauville, G., Lantz-Andersson, A., Mäkitalo, Å., Dupont, S., & Säljö, R. (2016). The carbon footprint as a mediating tool in students' online reasoning about climate change. In O. Erstad, K. Kumpulainen, Å. Mäkitalo, K. C. Schröder, P. Pruulmann-Vengerfeldt, & T.

Jóhannsdóttir (Eds.), *Learning across contexts in the knowledge society* (pp. 39–60). Rotterdam, the Netherlands: Sense Publishers.

- Fauville, G. (2017). Questions as indicators of ocean literacy: Students' online asynchronous discussion with a marine scientist. *International Journal of Science Education.*

2. Learning about the ocean

This chapter begins with a short summary of the history of research on ocean literacy and a reflection on where marine science education is situated in relation to science and environmental education. Following this, the chapter addresses two main questions that are integral to learning about the marine environment. The first question concerns the public understanding of the ocean and what research tells us about the state of ocean literacy among citizens of all ages. The second question considers how educational researchers have addressed ways to overcome some of the challenges of learning about the ocean.

A brief history of the emerging concept of ocean literacy

At the turn of the 21st century in the USA, concepts relevant to understanding the ocean were rarely taught in formal scienceeducation (Hoffman, Martos, & Barstow, 2007). This absence triggered top-down and bottom-up reactions aimed at implementing the legitimate role of the ocean in science and environmental education. The top-down approach came from two US national commissions calling for a more ocean-knowledgeable society. In 2003, the Pew Oceans Commission provided recommendations for a new marine policy and stated that:

> Through enhanced marine education and awareness, we can inspire the next generation of scientists, fishermen, farmers, business and political leaders – indeed all citizens – with a greater understanding and appreciation for the oceans. (p. 91)

The United States Commission on Ocean Policy (2004) also noted that "school curricula, starting in Kindergarten, should expose students to ocean issues, preparing the next generation of ocean scientists, managers, educators, and leaders through diverse educational opportunities" (p. 122).

The bottom-up movement to promote ocean science education started in 2002 with concerned scientists and educators, both in formal education and in other contexts, raising their voices against the lack of ocean science in school.

The USA community launched the so-called ocean literacy movement and discussed what they consider citizens should know about the ocean after completion of formal education in order to be considered ocean literate (Schoedinger, Tran, & Whitley, 2010). This was translated into a set of seven overarching ideas, referred to as the seven essential principles of ocean literacy (Figure 1), and with 45 fundamental concepts falling under the different principles[5].

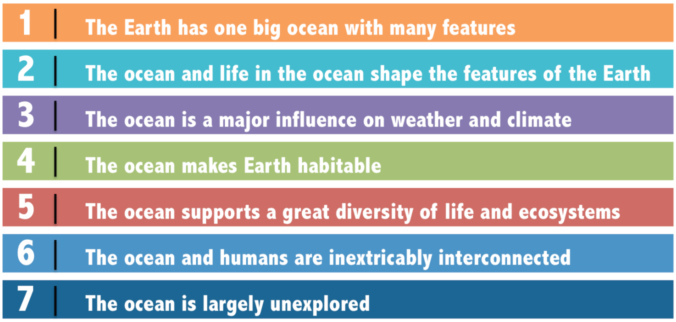

Figure 1. The seven essential principles of ocean literacy.

In 2011, the National Academy of Sciences started to update the science education standards (National Research Council, 2013). The ocean literacy community, led by the National Marine Educators Association (NMEA), raised its voice against the terrestrial bias that has always been present in science education, as can be seen in this excerpt from a letter addressed to the National Academy of Sciences:

> There is an overwhelmingly terrestrial bias to almost all the K-5 and Middle School Life Science standards. This takes the form of referring to living things as plants and animals, presenting plants as the only photosynthetic organisms on Earth, stating that animals need "air" to survive, describing decomposition as a process that takes place only in the soil, referring to photosynthesis as the only mechanism of primary productivity (ignoring chemosynthesis), etc. These oversights actually are factual errors, and result in incomplete or inaccurate treatment of many fundamentally important concepts. They also, if allowed to stand, unintentionally ensure that students will never be allowed opportunities to learn about the unique and ecologically important organisms that occupy the vast majority of the living space on Earth – in the ocean. (C. Strang, personal communication, March 12, 2015)

[5] Visit http://www.coexploration.org/oceanliteracy/documents/OceanLitChart.pdf for the complete list of ocean literacy concepts.

These protests sent by the ocean literacy community succeeded in promoting the ocean topics more than ever before in the standards (National Research Council, 2013), even if the terrestrial bias is still common in science education (Gotensparre et al., 2017; see also Study IV).

The same terrestrial bias exists in European science education, where ocean science is not a substantial part of the curricula (Gotensparre et al., 2017). While there are several marine education projects flourishing around Europe, their coordination and dissemination are made difficult by the complexities of different languages, educational policies, curriculum regulations and, in addition, ways of living by the seas. In 2012, the European Marine Science Educators Association (EMSEA) was created with the vision that European marine education needed a transformation and stronger international connections in order for teachers and educators to feel more supported, engaged and equipped for the task of making European citizens more ocean literate (Copejans, Crouch, & Fauville, 2012; Fauville, Copejans, & Crouch, 2013). Shortly after this, the European Marine Board (2013), outlining the marine thematic research priorities for Europe, recognised that Europe needed a consensus about how to enhance ocean literacy. Simultaneously, the interest of the European Commission in ocean literacy increased and two large-scale European projects aimed at promoting European citizens' ocean literacy were funded.

The term ocean literacy also became part of European and international declarations. For example, one of the goals of the Rome Declaration is to promote "a wider awareness and understanding of the importance of the seas and ocean in the everyday lives of European citizens" (EurOCEAN, 2014, p. 1). Moreover, the declaration calls for "sustained support for ocean literacy, best practice in science communication, citizens science initiatives and knowledge transfer to be embedded in marine research projects and programmes" (p. 4). On the international scene, the concept of ocean literacy appeared in the Galway Statement on Atlantic Ocean Cooperation (EU-Canada-USA Research Alliance, 2013):

> We further intend to promote our citizens' understanding of the value of the Atlantic by promoting ocean literacy. We intend to show how results of ocean science and observation address pressing issues facing our citizens, the environment and the world and to foster public understanding of the value of the Atlantic Ocean. (p. 1)

By signing this statement, Canada, Europe and the USA agreed to foster public understanding of the value of the (north) Atlantic Ocean through promoting ocean literacy. Regions such as Canada and Asia have also created their own associations dedicated to promoting ocean literacy. Along with NMEA in the USA and EMSEA in Europe, the Asia Marine Educators Association (AMEA), the International Pacific Marine Educator Network (IPMEN) and the Canadian Network for Ocean Education (CaNOE) contribute to a worldwide grass roots effort to foster ocean literacy (see Dupont & Fauville, 2017 for a more detailed history of ocean literacy). Finally, in 2017, the international community came together in New York for the first United Nations conference on the ocean. The aim was to discuss how to address the UN Sustainable Development Goal (SDG) on the ocean, SDG14, which is to "Conserve and sustainably use the oceans, seas, and marine resources". This conference resulted in a call for action, stating the importance of fostering "ocean-related education, for example as part of education curricula, to promote ocean literacy and a culture of conservation, restoration and sustainable use of our ocean" (United Nations, 2017, no page number). Therefore, this international document acknowledges the important role ocean literacy has to play in the protection of the ocean.

Marine education in relation to science and environmental education

Marine science education can be seen as a significant vehicle for developing ocean literacy, building on skills typically taught by science and environmental education. While science and environmental education often converge, each has a different primary focus, as explained by Wals, Brody, Dillon and Stevenson (2014):

> [while scientific education] might teach students how to monitor water quality, identify pollutants and understand technologies that can reduce pollution, environmental education would involve an analysis of circumstances and behaviors that caused the pollution, as well as identifying ways to clean up a river involving the local community, policymakers and industry. (p. 583)

Brody (1996) expressed the same dichotomy when explaining that natural sciences help us understand issues such as toxic waste or groundwater pollution but do not explain why society has created these problems or how to find appropriate solutions. He discussed how environmental education brings us closer to the ecological debate and the implications of policies for the environment by incorporating both natural and social topics (Brody, 1996).

In the past, science and environmental education have had a troubled relationship, described as "distant, competitive, predator-prey and host-parasite" by Gough (2002, p. 1203). However, we are now entering a collaborative era where researchers talk about "convergence" (Wals et al., 2014) or even "mutualism" (Gough, 2002). This convergence between environmental and science education can be seen in Figure 2, where Science, Technology, Engineering and Mathematics (STEM) and environmental education overlap. This illustration also places ocean science education[6] at the intersection of science and environmental education, as these two fields are essential to develop an ocean-literate population. If science and environmental education are to converge, marine science education seems to be a powerful field that could serve to facilitate their convergence and highlight the interconnection of the two. In this respect, this thesis is rooted in science as well as in environmental education, with both being essential to the promotion of ocean literacy.

[6] In this thesis, the terms "marine science education" and "ocean science education" are seen as synonyms and are used interchangeably.

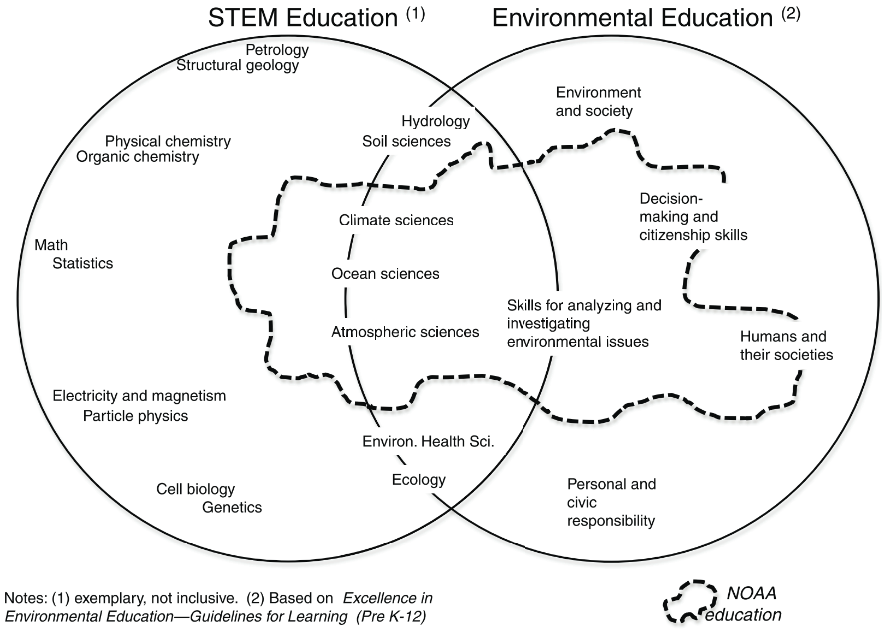

Figure 2. Relationship between science, environmental education, and NOAA education, with ocean sciences placed at the intersection (National Research Council, 2010, p. 35).

The challenges of participating in marine environmental debates

In order to participate in marine environmental debates, it is necessary to be able to communicate properly about the issues at stake with the other partners involved. The importance of communication in ocean literacy is inherent in the definition that an ocean-literate person "can communicate about the ocean in a meaningful way" (Cava et al., 2005, p. 5). As discussed further in Chapter 5, language, both written and spoken, is at the core of any scientific activity. Language allows scientists to formulate research questions, engage in research and negotiate and communicate their findings with peers and wider audiences. It allows policy makers to negotiate decisions and, also, allows citizens to join in societal debate about scientific issues (McGinn & Roth, 1999). Gyllenpalm (2010) and Lemke (1990) consider these to be activities pursued largely through "talking science". Engaging in scientific discourse is a challenging endeavour as it requires an understanding of how claims, definitions and explanatory models are developed and communicated (Gyllenpalm, Wickman, & Holmgren, 2010). Talking science requires much more than recalling definitions of concepts and facts; it requires an ability to apply concepts in a relevant way to make meaning (Lemke, 1990). The importance of talking science is at the core of this thesis as it explores how various digital platforms serve as contexts for promoting communication around marine environmental issues.

In this thesis, a socio-cultural perspective on learning is applied as a theoretical platform, where language plays a central role. Learning is seen as situated in specific activities where people interact with each other and by means of the mediating tools available, language being the most important one (Vygotsky, 1978; Wertsch, 2007).

Participating in marine environmental debates, even if equipped with good communication skills, remains a challenging exercise, as these issues are often very complex. Issues that concern the marine environment are first and foremost relatively new and therefore not always completely agreed upon or even fully understood by the scientific community itself, which makes them more difficult to grasp by the public. Environmental issues are also linked to human activities that are in themselves complex, rooted in the fabric of society where economy, health, freedom and equity are often intertwined. Given their complexity, there is a lack of simple and clear cut right or wrong answers; generally, we have to operate with a range of solutions that are more or less acceptable in different contexts and cultures, etc. Moreover, we are living in an era of rapid, and global, information propagation, offering the potential for reaching all kinds of audiences. This ability to reach large audiences can also be used in malicious ways, such as by the oil industry denying the carbon dioxide related issues or discrediting the scientific consensus (Dunlap & McCright, 2011). Spreading misinformation has become easier than ever and has a negative impact on citizens' trust in the scientific community and also causes confusion around these issues. The fictional documentary (also called mocumentary) *Mermaid: The body found*, aired on Animal Planet in 2012, is a striking illustration of this problem (for a deeper account of the kind of misinformation related to ocean science, see Thaler and Shiffman, 2015). This fictional documentary claims that not only do mermaids exist, but that the government is covering up their existence. The fact that alleged scientists uncovered this secret while governmental agencies (e.g. NOAA) are portrayed as antagonists, combined with professional visual effects, contributes to the credibility of the fictional documentary. Not only did this fake documentary score the highest viewer audience in the history of

Animal Planet (ABC News, 2013), it also triggered a huge wave of reaction on social media with a wide range of people being fooled (Thaler & Shiffman, 2015). In response to this show, NOAA had to release a statement to refute the existence of any kind of aquatic humanoids (National Oceanic and Atmospheric Administration, 2012) because, as bluntly expressed by ABC News (2013), "Enough people missed the disclaimer or missed basic science in high school". This illustrates how the seeds of "alternative facts" sprout more easily in the mind of citizens who lack basic understanding and knowledge of ocean science. In this respect, research in ocean science education has an important role to play in ensuring that each citizen has the appropriate knowledge and understanding of the ocean in order to become an agent of change in relation to marine environmental issues.

Ocean literacy among the public

Since the early eighties, a handful of researchers have been interested in finding out how familiar students and the public are with the marine environment. Different types of research have been carried out targeting various groups, as shown in Table 1.

Table 1. Overview of the different studies investigating how familiar citizens of all ages are with the marine environment and related issues.

Fortner & Mayer, 1983	Research object	Knowledge, attitude and experience in relation to the ocean and the Great Lakes.
	Research subject	1,887 5th graders & 1,786 9th graders in Ohio.
	Method	Survey: multiple choice questions & semantic differential scale.
	Findings	Knowledge score: 38 per cent for 5th graders & 48 per cent for 9th graders. Attitude: more positive toward the ocean than Lake Erie. Correlation between knowledge and attitude. Source of knowledge: movie and television.
Fortner & Mayer, 1991	Research object	Knowledge, attitude and experience in relation to the ocean and the Great Lakes over a period of eight years. Longitudinal study based on Fortner & Mayer (1983).
	Research subject	1979: 1,887 5th graders & 1,786 9th graders in Ohio (Fortner & Mayer, 1983), 1983: 1,944 5th graders & 1,579 9th graders in Ohio. 1987: 956 5th graders & 776 9th graders in Ohio.
	Method	Longitudinal study using the updated version of the survey from Fortner & Mayer (1983).
	Findings	Knowledge: slight increase in both grades in 1987 compared to 1979. Attitude: more positive about the ocean but general decline with time. Source of knowledge: shift from movie and television to formal education as main source of information.
Brody, 1996	Research object	Understanding of natural- and social-science concepts concerning Oregon's marine environment.
	Research subject	159 4th, 8th & 11th graders.
	Method	Group interviews.
	Findings	Low level of understanding of marine concepts. Series of misconceptions concerning photosynthesis and respiration in the marine environment.
The Ocean Project, 1999	Research object	Awareness, attitude and knowledge about the ocean.
	Research subject	1,500 USA adults.
	Method	Six focus groups. Telephone survey.
	Findings	Positive attitude toward the ocean. Superficial knowledge of the ocean and its function. Little awareness of the health of the ocean.

Table 1. (*Continued*).

The Ocean Project, 2009 & 2011	Research object	Awareness and knowledge about the ocean.
	Research subject	USA adults.
	Method	Similar survey to The Ocean Project (1999).
	Findings	Knowledge remained consistently low. Problem to admit that the ocean is threatened. Difficulty to connect climate change to the ocean.
The Ocean Project, 2012	Research object	Awareness and knowledge about ocean acidification.
	Research subject	1,817 USA adults.
	Method	Survey.
	Findings	Low percentage of participants has heard about OA.
Steel et al., 2005	Research object	Ocean literacy among the public.
	Research subject	1,233 USA adults in 48 states.
	Method	Mail survey.
	Findings	1/3 of respondents considered themselves not well informed about the ocean. Low percentage of correct answers concerning the ocean in knowledge questions. Main source of information: television, radio, Internet and newspapers. Negative correlation between use of television and radio as source of information and knowledge. Positive correlation between the use of Internet as source of information and knowledge.
Ballantyne, 2004	Research object	Conceptions of the marine environment.
	Research subject	54 10–11-year-old students in Cape Town, South Africa.
	Method	Interviews in groups of five to seven students.
	Findings	Ability to name a wide range of marine species and concepts (e.g. tides). Wide range of misconceptions concerning the relationship between the marine concepts.

Table 1. (*Continued*).

Guest et al., 2015	Research object	Ocean valuation, knowledge, interaction and interest of public school students aged 12–18.
	Research subject	723 students in grades 7th to 12th in Nova Scotia, Canada.
	Method	Survey with multiple-choice and open-ended questions.
	Findings	Low level of knowledge. Higher graders have significantly higher score than lower graders. Positive correlation between the knowledge and the ocean valuation. Positive correlation between coastal activities and knowledge.
Fletcher et al., 2009	Research object	Awareness of marine environmental issues.
	Research subject	Visitors to the National Maritime Museum.
	Method	Interviews.
	Findings	Strong interest and reasonable factual knowledge.
Jefferson et al., 2014	Research object	Knowledge and interest in UK marine species. Perception of the health of the ocean. Interaction with the marine environment.
	Research subject	1,047 adults from the UK.
	Method	Survey.
	Findings	Knowledge gap regarding UK marine diversity. Pessimistic attitude toward UK seas.
Corner et al., 2014	Research object	Awareness, knowledge and concern of OA.
	Research subject	2,501 adults.
	Method	Two online surveys.
	Findings	1/5 of the participants has heard of OA. Among these, low self-reported knowledge. Participants evenly split on whether they could personally help mitigate OA.

These studies, from around the world and spanning almost 40 years, make use of various empirical materials, dominated by surveys, to shed light on different aspects of how familiar citizens are with the marine environment. The subjects of these studies range from 5th graders to adults and the research was carried out in various sites, from school to public aquarium visits. While the studies vary greatly in their approach, the vast majority reach a similar conclusion: there is a low level of understanding of the marine environment. This conclusion is, for example, expressed in relation to students of various ages in the following terms: "Students tested had low levels of knowledge regarding marine and aquatic topics" (Fortner & Mayer, 1983, p. 223) and "The level of understanding of basic concepts and principles related to marine ecosystem dynamics, resource use, management, and decision-making processes is low" (Brody, 1996, p. 26). Researchers focusing on adults draw the same kind of conclusion, citing "low levels of ocean literacy and lack of a sense of urgency" (The Ocean Project, 2009, p. 2) and "The public is poorly informed on many ocean and coastal policy issues" (Steel et al., 2005, p. 107).

While formal education offers an essential means to increase citizens' knowledge of the ocean, a pan-European survey gathering more than 10,000 responses revealed that European adults rely primarily on television (82 per cent) as a source of information about the marine environment, followed by the Internet (61 per cent) (Gelcich et al., 2014). The importance of the Internet as an evolving space that offers possibilities for developing ocean literacy aligns with the focus of my thesis, i.e. investigating into the learning opportunities offered by different online communication platforms.

Despite the fact that it seems difficult for citizens to take ownership of the issues relating to the marine environment, it is important to remember that in the current society marine issues constitute only a very small portion of what citizens are expected to be familiar with and have opinions about. Citizens are now expected to participate in and take responsible decisions on a wide range of topics concerning, for example, human health (e.g. vaccination), food choice (e.g. genetically modified organisms) and energy consumption. Thus, citizens need to be knowledgeable about a wide range of topics in order to be considered responsible actors. Therefore, it is not surprising that engagement with the rather recent field of marine-related environmental issues, in comparison with terrestrial and atmospheric issues (e.g. deforestation and the ozone hole), is proving challenging for many. Since being able to participate in debates concerning the health of the ocean is a relatively new responsibility for citizens, it is of utmost importance that the educational research community takes responsibility by investigating how education inside and outside the classroom can support the development of citizens' ocean literacy. The aim of this thesis is to provide a contribution towards this important goal.

Challenges for marine science education

As stated above, research indicates that citizens are relatively unfamiliar with the marine environment and related issues. Here, I will reflect on how educational research can support citizens in general, and students in particular, to develop their ocean literacy. In this context, it is important to note that to date little attention has been given to research in marine education (Uyarra & Borja, 2016). The corpus of research in the field of marine education is sparse and although a number of publications describe related teaching activities, they do not study the learning processes or outcomes. According to the online subscription-based scientific citation index service Web of Science, there have been only 91 publications addressing the topics of "ocean literacy", "marine education" or "ocean education" since 2000 (Figure 3).

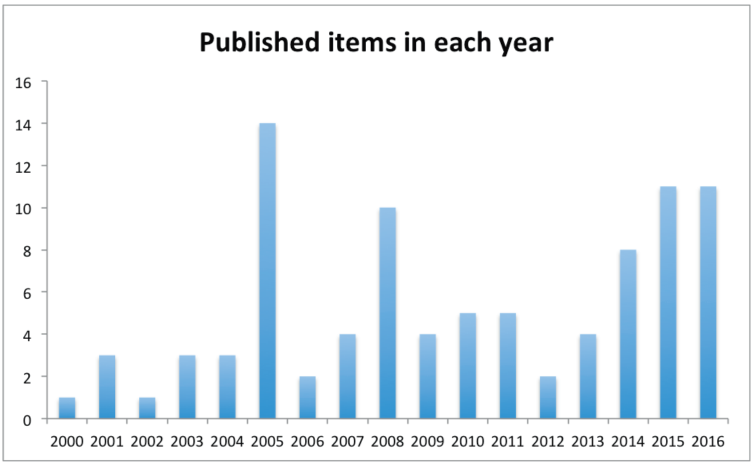

Figure 3. Number of published papers including the topics "ocean literacy", "marine education" or "ocean education" since 2000.

This field of research is still relatively new and undeveloped because of the various challenges encountered by marine science education, as already touched upon in Chapter 1. First and foremost, in many regions, the ocean is not attended to as part of schooling (Gotensparre et al., 2017). This initial challenge can be understood partially as a result of the difficulty in accessing the ocean. Because few people have the ocean in their backyard, first-hand exploration of the ocean as part of formal instruction becomes a challenge in terms of time, safety and budget (Gotensparre et al., 2017). Guest and her colleagues (2015) show that students who reported a high number of ocean activities also scored higher on the multiple-choice questions about ocean principles and concepts. Fortner and Mayer (1983) reported that students in coastal areas scored higher. But even when citizens are at the seashore, most of the marine environment remains hidden under the surface and far away from the coasts, leading to a situation where only a small fraction of the marine diversity and processes can be encountered and experienced directly. As expressed by Longo and Clark, "the ocean is commonly viewed as something far removed from human society. In some way, it is deemed 'out of sight, out of mind"' (2016, p. 465).

Moreover, the inherent complexity of marine environmental issues makes trying to understand them an arduous task. The functioning of the marine environment is rooted in intricate connections between ecological, chemical, physical, biological and social processes (EurOCEAN, 2014). This interplay of various components is made even more complex by the fact that there is only one ocean covering most of the surface of the planet. To understand this massive three-dimensional system, one needs to be able to navigate all the way from small-scale observations and knowledge to macro-issues. It is necessary to grasp important connections such as those between tiny organisms (e.g. microbes) and worldwide phenomena (e.g. the carbon cycle).

Potential solutions for marine science education

Field trips

In order to address the distance between students and the ocean, Cummins and Snively (2000) designed a learning activity unit consisting of 26 4th graders in Canada and lasting a period of eight weeks. The students visited a local beach and nearby marine ecology station. A broad range of data was collected to evaluate the effects of this instruction on the students' learning. The data corpus included field observations and student log books as well as a series of questionnaires addressing the students' familiarity with the marine environment (e.g. frequency of visits to the seashore), their attitude toward the ocean, their marine scientific knowledge and their stances (preservationist, conservationist or exploitative) toward the ocean. The result of this study showed that the emphasis on experiential learning and direct contact with the marine environment through field trips to the seashore led to a significant increase in knowledge and positive attitudes toward the ocean.

Greely (2008) also explored the impact of direct contact with the marine environment as she followed 30 girls, aged 13–14 years, during an Oceanography Camp for Girls. This camp provided ocean-learning experiences in natural settings, access to research facilities and discussions with scientists. Three quantitative instruments were used to evaluate the participants' (1) ocean literacy and engagement, (2) ocean stewardship and (3) ocean environmental morality. In the results, it was argued that direct and personal experience with nature in general, and with the marine environment in particular, positively influenced the students' knowledge of and reasoning about socioscientific issues of this kind and, in addition, strengthened their "environmental morality" (p. 19).

More recently, Sattler and Bogner (2016) studied the impact of a field trip to a local zoo on students' knowledge about the marine environment. The study consisted of 117 students aged 15–17. This field trip focused on marine mammals such as manatees, harbour seals, California sea lions and polar bears and their natural habitats, along with the anthropogenic threats (e.g. climate change and overfishing) on these marine habitats. To measure the students' knowledge, a questionnaire consisting of 16 multiple-choice questions was administered one week before the field trip, immediately after the trip, and then six weeks later. The data analysis indicated a significant increase in knowledge after the zoo field trip. The highest knowledge score was immediately after the field trip but the level of knowledge six weeks after the field trip was still significantly higher than the pre-test level. The pre-test indicated that the students had hardly any prior knowledge about marine mammals, marine ecosystems and anthropogenic influence. An important finding was that the students with previous visits to the zoo had more prior knowledge and learned more than the students for whom this was their first visit. The authors suggest that field trips to a zoo give citizens access to an ecosystem and animals that they would never be able to encounter in their everyday life, and conclude that zoos can supplement formal education in terms of environmental education.

Virtual immersion

While these three studies are strong advocates for student field trips, showing the positive impact of direct contact with the ocean (and marine scientists), they do not offer solutions for populations living far away from the shore or far from an aquarium. Neither do they present any suggestions on how to enable students to investigate the ocean under its surface and be in contact with marine organisms. One solution to this challenge may be found in digital technologies that hold the potential to mimic exploration of the marine realm. Tarng and his colleagues (2008) (see also Study I) created a virtual marine museum for elementary education in Taiwan. The virtual museum was divided into four sections:

- Transparent tunnel displaying large marine specimens, such as shark and tuna.
- Freshwater area displaying freshwater fish species from different Taiwanese ecosystems, such as creeks and dams.
- Seawater area displaying seawater fish species from different ecosystems, such as tidal zones and coral reefs.
- Breeding area for visitors to breed their own virtual fish.

Tarng and his colleagues (2008) tested the virtual museum with three teachers and six students from 5th and 6th grades. The data consisted of in-depth interviews with teachers and students and observations carried out by the researchers. The results of the study showed that the students were interested in the virtual museum and considered it more enjoyable than a textbook. Even though the teachers in the study believed that this kind of activity had many advantages (e.g. motivating learners and avoiding problems associated with field trips), they also encountered technical problems that could make students lose patience or interest. However, one could argue that technology has become much more user friendly and stable since this study was carried out, so the likelihood of these technical challenges occurring now is much reduced.

More recently, researchers investigated an immersive virtual environment where users wore a head-mounted display and played the role of corals on a rocky reef, exploring how ocean acidification (OA) endangered the marine life around them (Ahn et al., 2016). In the first experiment, 53 participants ranging from 18 to 37 years were randomly assigned to the treatment group using the head-mounted display with a haptic component to experience OA, while the control group experienced OA through watching a recording of the previous participants in the treatment condition. It is argued that this kind of immersive experience of the marine environment leads to an increased perception of spatial presence (the user's physical body feels in sync with the movement of the virtual environment), body transfer (the illusion of body ownership), and to an increase in the extent to which users incorporated images of nature when thinking about themselves (Inclusion of Nature in Self [INS]) (Ahn et al., 2016, p. 403). A similar experiment was run with 126 participants without the haptic feedback for the treatment group. In this study, while the spatial presence and body transfer were greater in the treatment than in the control group, the INS was similar for both groups. The authors argue that digital technology has the potential to engage individuals with marine environmental issues, but they also conclude that technology alone is not sufficient to induce the sense that nature is part of the self.

Hands-on experimentation

Marine educators and researchers have also investigated how to help students grasp the complexity of marine environment issues through the development of hands-on experiments and activities, where students can manipulate real-time marine data to understand the interconnectedness of the different parameters involved.

The Center for Microbial Oceanography: Research and Education (C-MORE) designed and tested a series of hands-on kits containing all the supplies, paper and electronic materials (e.g. reading, video and PowerPoint presentations) necessary to run their activities. These kits, targeting audiences from elementary to high school, were lent to teachers for free through a system of local lending libraries situated in four USA states (Hawaii, California, Massachusetts and Oregon). Some of the topics covered by the material were OA, random sampling and marine debris. In order to evaluate the impact of these hands-on activities, a mixed-method study was conducted (Foley et al., 2013). First, 45 teachers completed a written evaluation using Likert scales and open-ended questions concerning their experiences with the material. The quantitative and qualitative data collected from these evaluations indicated a high degree of satisfaction with the kits among the teachers. Second, the student learning was investigated in partnership with six middle and high schools in Hawaii, with a total of 1,236 students using five different kits. Using the surveys included in the material, that is multiple choice and true–false questions, the students' knowledge, comprehension and application of the topics were investigated. The surveys were administered immediately before using the kit (pre-test), immediately after using the kit (post-test 1) and then approximately two weeks later (post-test 2). The data showed a significant gain between pre- and post-test 1. Comparisons between pre- and post-test 2 revealed a significant increase in scores, indicating that even two weeks after instruction knowledge was retained. Finally, there was no difference in scores between the two post-tests. Although this study did not investigate the topic covered by the teachers before and after the use of the kit, these results indicate that the use of the kits (along with the regular teaching practice) significantly helped the students to gain understanding of these complex marine issues and thus increased their ocean literacy.

Virtual experimentation

As demonstrated above, hands-on activities are valuable in teaching practices that aim to develop students' content knowledge as well as their understanding of the scientific method. However, some experiments are difficult to run in a classroom due to safety, time or budget constraints. In this respect, virtual laboratories offer an important means to conduct experiments and to understand the interplay between different marine processes.

The virtual laboratory used in Study IV makes it possible for students to test the effect of OA on sea urchin marine larvae and to reflect on the cascade effect a modification of the acidity would have on the food chain and the whole ecosystem (see Chapter 5 for in-depth description of this tool). A preliminary study of this virtual lab (Fauville et al., 2011) investigated its effect on the growth in knowledge of 15 Swedish and 15 Californian high school students by giving them pre- and post-tests with multiple-choice questions targeting their understanding of OA. The findings showed a significant increase in post-test scores, indicating that the virtual lab seemed to promote understanding of OA.

Later, a large-scale research study was conducted in California in order to investigate how students pick up concepts and modes of reasoning after using the aforementioned virtual laboratory (Petersson, Lantz-Andersson, & Säljö, 2013a). Along with using the virtual lab, 500 students were given a pre- and post-test with an open-ended question, which required them to suggest, and elaborate on, an experiment to study how a change in acidity could affect a population of corals. Out of the 500 participants, a sample of 80 students' pre- and post-tests was randomly selected for data analysis. The first analysis showed that the students used more scientific concepts on the post-test. The answers from the students were also categorised on a scale from one to five, according to the degree of understanding displayed in the answer (from not understanding what characterises an experiment [Category 1] to being able to outline a relevant experiment that would answer the question of how corals would be affected by changes in acidity [Category 5]). The comparison of pre- and post-test ranking showed that 47.5 per cent of the students' answers remained in the same category, while 43.5 per cent of the students provided an answer that was assessed as a more developed understanding in the post-test. The remaining 9 per cent of the students wrote an answer of a lower level in the post-test. Since about half of the students developed their understanding after using the virtual lab, Petersson and her colleagues argued that the virtual lab seems to have the potential to trigger learning about how to design an experiment relating to a marine problem.

In another study of the same virtual lab, Petersson, Lantz-Andersson and Säljö (2013b) video-recorded 19 Swedish high school students engaging with this laboratory in small groups. The interaction analysis of the material showed that the students engaged with the virtual lab in relation to the scientific content, but also in relation to the functionalities of the tools by using a trial-and-error method to achieve some of the tasks. By pinpointing the unintended actions taken by the students, the researchers argued that the virtual environment alone cannot determine the learning outcome, rather the learning is a consequence of the activities in which the students participate, which include interacting with the teacher and their peers as well as working with the virtual lab.

Manipulation of real-time data

In a series of publications, Adams and Matsumoto (2007, 2009, 2011) discussed the opportunities for students from middle school to undergraduate level to explore real-time data on parameters such as tide, concentration in nitrate and salinity. This activity seems to have engaged students in inquiry processes and fostered discussion with the researchers who collected the data. The students were also encouraged to build their own inexpensive observation buoys with sensors and analyse the data in their classroom according to the questions they themselves had formulated in an inquiry process. The authors argue that this kind of activity facilitates contact between scientists and students and contributes to developing a sense of community between these parties and also between the students and their environment (for those living by the coasts). The authors also address the lack of time faced by teachers when striving to implement this type of project in school and suggest ensuring that the use of real-time data aligns with the standards. Adams and Matsumoto concluded that "our classroom trial demonstrated that ocean literacy awareness in students can be improved by using real-time data and that, through these types of activities, students can experience the ocean in classrooms all over the country" (2009, p. 9).

In summary, the aim of this section is to provide insight into the field of research related to the possibilities for promoting ocean literacy despite the challenges presented by the ocean as an object of knowledge. While this is not an exhaustive literature review, it illustrates the scarcity of research in the field of marine education and demonstrates that much more is needed. This thesis enriches the field by investigating how digital platforms can interplay with the effort to overcome the distance and complexity of the ocean, thus contributing to citizens' development of ocean literacy. As demonstrated above, research in marine education consists mainly of impact studies, focusing on the outcomes of learning related to particular aspects decided on beforehand. The theoretical basis of this thesis considers knowledge as developing through participation in practices and interaction. In consequence, communication is argued to be a central component for learning (Vygotsky, 1986; Wertsch, 1998; Säljö, 2000). While most of the previous studies have focused on the outcome of instructional activities, this thesis proposes a new approach to the field of ocean literacy by focusing on the process of learning about the ocean through communication that takes place in different online settings.

3. Learning and digital technologies

In this chapter, I will first review some of the literature aligning with each of the four studies included in this thesis. Following this, I will discuss the challenges related to the use of digital technology as a means of promoting ocean and environmental literacy.

Digital technologies in our everyday life

As discussed in the previous chapter, for our society to function sustainably it is necessary for citizens to become versed in a wide range of topics to enable them to make sound decisions about their lifestyle on a daily basis. Over the past 60 years, digital technologies have made access to knowledge and information easier for citizens and they are now ubiquitous in our lives. By penetrating most parts of our work routines, digital technologies have transformed the way we communicate and organise our meetings with our colleagues next door or on the other side of the planet. Our leisure-time activities have also changed, now that we are able to do most of our errands, such as grocery shopping, choosing our next holiday or taking care of our finances, without leaving the comfort of our home. Digital technologies can also help us stay healthy by, for example, tracking how many steps we take daily, providing workout routines specifically tailored to the individual user and by offering reminders and gratification systems. In the supermarket, technologies can help us learn about the ecological and social footprint of the different goods available on the shelves. Thus, digital technologies have permeated most of our daily activities. They have also evolved from fixed, slow and bulky gadgets to highly mobile units that can be held in the palm of the hand. For the younger generation, digital technologies are a natural and integrated element of almost all activities and as such "part of the taken-for-granted social and cultural fabric of learning, play, and social communication" (Ito, 2010, p. 11).

An important characteristic of digital technology is its multimodality, able to include texts, images, animation and sound, creating rich and engaging experiences through a steadily growing supply of applications. The multimodal nature of digital technology makes it possible to visit remote places virtually (Jacobson, Militello, & Baveye, 2009), run experiments (Petersson, Lantz-Andersson, & Säljö, 2013a) or visualise invisible phenomena (Ryoo & Linn, 2014). An example of an invisible phenomenon, described in Chapter 1, is the emission of greenhouse gases, which can be made visible through digital representations. Citizens need to be knowledgeable about the consequences of their everyday behaviour in terms of CO_2 emission in order to be able to act responsibly. The concept of the carbon footprint[7] (CF) is one of many examples of how technology mediates advanced knowledge of an invisible phenomenon that otherwise would be out of most people's reach. In other words, digital technology has transformed how we engage with information by enabling new kinds of learning activities (Lantz-Andersson & Säljö, 2014). Since technology is now something we carry with us in our pockets, staying connected even when not actively using our devices, the access to information and opportunities for learning are becoming more fluid and mobile (Kumpulainen & Sefton-Green, 2012). This form of boundary crossing blurs the demarcation between in and out of school learning (Bulfin, Johnson, Nemorin, & Selwyn, 2016) and suggests that schools no longer have a monopoly on information and knowledge. We now live and learn in what Breck (2006) calls "the virtual knowledge ecology":

> Established education no longer controls the primary substance of what its students are supposed to be learning. That substance has been liberated from geography. Knowledge now flows in the limitless Internet, where it is mixed, enriched, and evolves freely as the virtual knowledge ecology. (p. 115)

Envisioning opportunities for learning as flowing between contexts aligns with the approach used in this thesis, where the four studies analyse communication in learning activities about (marine) environmental issues in different settings. These studies take us across different environments for learning, such as outdoor activities and museums (Study I[8]), the Facebook page of a renowned marine research institute (Study II[9]), an online discussion forum gathering students from around the world (Study III[10]) and an online

[7] The carbon footprint is the amount of carbon dioxide and other greenhouse gases that is emitted by a person's lifestyle, an organization's operation or a product's manufacture and transport.
[8] Study I is a review of the literature on the use of digital technologies in environmental education.
[9] Study II, where I scrutinised the use of the Facebook page of a marine institute.
[10] Study III, where I observed the comments from students discussing their previously estimated carbon footprint.

asynchronous discussion between students of a class and a scientist (Study IV[11]).

During recent decades, digital technologies allowing more interactivity, such as creating, sharing and retrieving information and media, have made their way into schools. The expectations from all kinds of stakeholders on how these technologies would improve learning outcomes were extremely high, for example it was assumed that digital technologies would increase communication, deepen students' understanding of the concepts studied and increase their motivation (Breck, 2006; Bingimlas, 2009). Despite the amount of money invested in implementing technologies in schools, and the extensive research carried out on this topic, it has been quite difficult to find tangible proof that technologies significantly improve student academic performance, at least as it is traditionally measured. But, perhaps more significantly, such resources change the way we learn, remember, find and manipulate information and engage in many other activities (Säljö, 2010). However, the research on digital technology in instructional practices is too extensive a field for this thesis. Thus, I will focus on research that is relevant to each study.

Digital technology in environmental education

In Study I, published in 2013, I present examples of digital technologies used in environmental education instruction, in order to discuss the potential impact of these technologies on teaching and learning and to give an overview of how this field of research has emerged and how it is developing. To update this review, I will present in this section some of the most recent studies in order to see how the field has evolved.

In 2016, Kacoroski, Liddicoat and Kerlin investigated the use of iPads for outdoor environmental education. They were specifically interested in the attitudes, behaviours and comprehension of children using iPads. In this study, grounded in a social constructivist framework of learning, the children made use of the Water Quality App, designed as a collection instrument to promote children's learning, during the outdoor activity and after the field study. The research was conducted at a nature centre in the USA by following nine groups[12] of 5th graders learning about watershed and water quality by

[11] Study IV, where I analysed the questions formulated by students during their asynchronous discussion with a scientist.
[12] The total number of students is not specified by the authors.

collecting invertebrates in a river. The iPads replaced the paper worksheet where the students usually gathered their notes concerning the living organisms they collected. The authors conducted observations throughout the activities. The analysis of the data collected showed that students reacted with excitement when informed that they were about to use mobile devices, but this initial interest seemed to fade rapidly. The device created some tension among students as they found it difficult to share. In all groups, the natural world changed the students' attention and moved it away from the device when, for instance, macro invertebrates were escaping from their buckets. Some students and adults had problems navigating the app, but instead of receiving help from another adult, students were prompted to help the less-knowledgeable person. Besides using the iPad to record their data, the students used it in groups to learn about different organisms. During the debriefing part of the programmes, the students made use of the device by referring back to it while answering questions, suggesting that it had a mediating role in the students' learning process. Kacoroski and her colleagues (2016) argued that their research provided some knowledge concerning how children interact with each other and with nature when using mobile devices in an outdoor programme. They concluded that mobile devices should be integrated into outdoor education as an educational instrument but should not be the focus point of the activity.

Another kind of technology that has attracted increasing interest in the science education community since Study I was published is the Geographic Information System (GIS), which enables large quantities of geographical data to be visualised in dynamic ways (Kerski, Demirci, & Milson, 2013). GIS is argued to support student-centred, problem-based and inquiry learning and also to promote decision making by facilitating the study of current issues relating to social and scientific concepts (Kerski, 2008). Xiang and Liu (2016) argue that students need to develop their conceptual spatial–temporal skills in order to understand the important geographical changes caused by globalisation, making them more skilled to respond to and live in our changing society. In their study, Xiang and Liu used Google Earth as a GIS data platform, with 80 high school students in Singapore. The authors compared the effectiveness of learning with Google Earth versus "traditional instruction" (p. 67). All students received similar worksheets to complete the assignment. The students in the treatment group (using Google Earth) worked in front of their computers while students in the control group referred to the geography textbook. The skills developed during this activity were measured through an essay-based question, administered during a pre- and post-test to both groups. Additionally, the students in the treatment groups completed a short survey after the activity concerning the use of Google Earth. The analysis revealed that students in both groups did better at describing and analysing spatial changes in the post-test compared to the pre-test. The treatment group outperformed the control in their ability to identify and describe changes. The students in the treatment group stated that manipulating the data engaged them in active thinking and comparison activities. Furthermore, the students highlighted the importance of the timeline and the scaling options to see change over time and outside of the zone on which they were focused. The authors conclude that the use of Google Earth enabled visualisation and analysis of spatial data, which had a positive impact on the high school students' spatial and temporal thinking.

Finally, a recent study investigated how to improve students' attitudes and knowledge toward pollinating animals such as bees (Schönfelder & Bogner, 2017). Because bees often scare people, the authors investigated how effective digital encounters with these insects might be with regard to environmental attitude and knowledge in comparison with real encounters. A sample of 402 school students was divided into three groups: 162 students aged 10–13 participated in an educational programme involving the use of a borrowed beehive on the school grounds and four hands-on workstations covering the construction of honeycombs, bees' communication, usefulness to humans and nature and the negative human impacts on them. 192 students aged 13–15 participated in an eLearning programme consisting of four units covering the same topics as the hands-on workstations in the previous group. Instead of visiting the beehive, these students used an interactive online tool live streaming images from cameras installed at different angles inside and outside a beehive. An additional group of 48 13–15-year-old students did not participate in any of the programmes and served as a control group. The participants took a knowledge test one or two weeks before the beehive programme (T0), immediately after the programme (T1), and six to nine weeks after completion of the programme (T2). Students also answered questions concerning their attitude toward bees' conservation on a Likert scale. An additional group of 48 13–15-year-old students did not participate in any of the programmes and served as a control group. These students in the control group answered the same questionnaire twice (T0 and T1) but without participating in any specific enducational programme. While the control group did not display any increase of knowledge, the students participating in the programmes did increase their knowledge significantly. However, no clear relationship between attitude and knowledge could be found in the study. The authors conclude that both approaches show the potential to increase topic-specific environmental knowledge and argue that the virtual strategy constitutes a great opportunity for overcoming obstacles to experiencing the natural world, such as fear, disgust, time and budget, etc. The studies above illustrate the wide-ranging aspects of environmental education that can be promoted through the use of digital technologies.

Fostering discussions on Facebook

Study II investigates how communication and learning about the ocean are mediated through the Facebook page of a renowned marine institute. In this section, I report on the previous research scrutinising the discourse emerging on Facebook.

Learning-related discourse

As argued by Aaen and Dalsgaard (2016), three "Facebook spaces" have emerged from the use of Facebook in education. These spaces will be elaborated on below.

The first space is "Facebook as an institutional system" (Aaen & Dalsgaard, 2016, p. 162), where institutions such as schools administer Facebook groups with teachers and students as participants. These Facebook groups are often used as learning management systems (LMS), moderated mainly by teachers (e.g. Albayrak & Yildirim, 2015; Meishar-Tal, Kurtz, & Pieterse, 2012; Wang, Woo, Quek, Yang, & Liu, 2012). Drawing on virtual ethnography and qualitative interviews, Bosch (2009) argued that students prefer having discussions on Facebook to instructional LMS. Facebook groups have also been studied for educational purposes beyond their potential role as LMS. Lantz-Andersson, Vigmo and Bowen (2013) conducted an ethnographic study of a Facebook group, gathering 60 voluntary students aged 13 to 16 years from Colombia, Finland, Sweden and Taiwan as part of their English-learning classes. The data consisted of the posts and comments written by the students. The authors argued that despite the fact that the Facebook group was intended to promote everyday life rather than academic discussions, the posts published still often resembled the discourse one would find in a school task. According to the authors, the posting "could be understood as a response to a traditional school task, and displays very little of the common language use and dynamics characteristically found in communication on social network sites" (p. 303). However, in this study, as the interactions in the Facebook groups evolved over time, students started engaging in a more vernacular use of language. The authors argued that this transformation can happen if the students take increasing ownership of the Facebook group and become "in command" (p. 309) of the space.

The second space is "Facebook as social network site" (Aaen & Dalsgaard, 2016, p. 163). Studies have looked at non-institutional use of Facebook among students and its potential to support learning. Madge, Meek, Wellens and Hooley (2009) surveyed undergraduate students in a British university and found that "students thought Facebook was used most importantly for social reasons, not for formal teaching purposes, although it was sometimes used informally for learning purposes" (p. 141). Selwyn (2009) conducted a qualitative analysis of the Facebook activity of 909 undergraduate students in a UK university. His analysis revealed five types of emerging behaviours in relation to the participants' education: (1) recount and reflect on recent university experience, (2) exchange of logistical information concerning being an undergraduate, (3) exchange of academically oriented information, (4) seek moral support with regard to the undergraduate life, and (5) humorous comments about their studies. These five categories show that the education-related discussions are mainly used by students to engage in identity work as students rather than in learning per se. It is important to note that the education-related exchanges in this study are a minor constituent of all the postings analysed. In conclusion, the nature of the education-related discussions along with their sporadic appearance indicates that this kind of space does not have a significant influence on the students' engagement with their studies (cf. Adalberon & Säljö, in press).

Finally, the third space is the "student-managed Facebook groups" (Aaen & Dalsgaard, 2016, p. 160), which has been investigated in order to analyse the educational potentials of private Facebook groups managed by high school students. Aaen and Dalsgaard (2016) examined six student-managed groups and analysed 2,247 posts and 12,217 comments posted in these groups. The researchers also conducted group interviews with students from 17 Danish upper secondary schools and administered a survey to 932 students from 25 schools. Aaen and Dalsgaard (2016) argue that the student-managed Facebook groups can play an important educational role when used as a platform for receiving help on school assignments. The researchers conclude that Facebook groups constitute a space where students blend personal, social and academic life.

These studies all have an interest in understanding the kind of discourse students engage in when joining the different spaces organised on Facebook and the potential for learning. While the "Facebook as an institutional system" space leads mainly to academic discourse, Lantz-Andersson et al. (2013) demonstrated the difficulties in prompting students to engage in a more vernacular and everyday discourse. However, in the "Facebook as social network site" space, the discourse observed by Madge et al. (2009) more resembled that which Lantz-Andersson et al. (2013) found missing in the first space, that is vernacular interactions. In this second space, the academic topics were not significantly addressed, making it difficult to ascertain how much this kind of space can contribute to learning. Aaen and Dalsgaard (2016) argued that the third space "student-managed Facebook groups" is anchored in social life more than academic life and allows for discussion of social life and schoolwork. This echoes Lantz-Andersson et al.'s (2013) analysis of the fact that the students' discourse became less academic when they started to take ownership of the space created by teachers and intended for academic tasks. Interestingly, while these studies address the discourse and learning potential of Facebook groups and profiles, Facebook pages, such as the one in Study II, have not been investigated with the same educational lens. As ownership of the space seems to be an important component, one can argue that Facebook pages administered by an organisation where users are categorised as fans might prevent more authentic and personal discussions.

Fostering of pro-environmental discussions

Another important aspect of Facebook is its potential to promote environmentally friendly attitudes and behaviours. Robelia, Greenhow and Burton (2011) studied the implications of Facebook users' involvement in a Facebook application called Hot Dish. This application was designed to distribute and discuss climate change related news and to engage users in pro-environmental challenges. The data collected in this study originated from four sources: First, the statistics of the 346 users, which were tracked during a period of eight weeks. Second, surveys taken by 111 Hot Dish members, which mainly enquired about the users' online habits, environmental knowledge, attitudes and behaviours. Third, two online focus groups with eight participants in each. The first focus group was conducted with high and moderate users of the application while the second involved the more sporadic users of the application. The focus groups were mainly aimed at getting a better understanding of the users' motivation and usage of the Hot Dish application. Fourth, the users' comments posted on the application were analysed in relation to learning and behaviour changes. Interestingly, despite their high level of understanding of the environmental issue in question, the users held some common misconceptions, such as confusing ozone layer and greenhouse effect, or not recognising methane as a greenhouse gas. The study revealed that participants value the possibility offered by the application to share their opinions and to discuss with like-minded people. Participants also highlighted feeling safe to comment and to ask questions within this group of people with similar environmental views. Furthermore, the users declared that they valued the various opinions of Hot Dish users, even the ones they did not agree with, as they helped them gain new perspectives on different aspects of climate change. As described by Robelia and her colleagues (2011), the Hot Dish users stated that they learned pro-environmental strategies, such as those concerning vegetarianism or how to avoid processed food, from other users. Even though it was not the focus of Study III, we also observed the prevalence of dietary advice in the students' discussions. Hot Dish participants reflected, too, on how the dialogue invited them to engage in more writing and reading, which helped them to synthesise the information. The importance of synthesising information and formulating one's own opinions in order to move further in their understanding are salient characteristics of the asynchronous online discussion investigated in Study IV.

Online discussion fora

Study III focuses on an online discussion forum as a platform for students to reflect on their carbon footprint, estimated by the carbon footprint calculator (CFC). In formal education, the discussion fora are often used for a specific task, involving less emphasis on social aspects that emerge more naturally from other platforms that learners might already be familiar with and use on a daily basis, such as Facebook (Hou, Wang, Lin, & Chang, 2015).

Several studies have compared the learning potential of online discussion fora to other online environments. For example, Jose and Abidin (2016) looked at the impact of synchronicity and asynchronicity of this kind of discussion. They investigated the lexical richness of 56 adult students involved in English classes and using either an asynchronous or synchronous online discussion platform. The students were prompted to discuss or write about 10 topics relevant to their social and academic context over a period of 10 weeks. The quantitative analyses did not show any significant difference between the two treatments. Hou, Wang, Lin and Chang (2015) argued that the learners' social knowledge construction behaviours might differ due to the social contexts in which students interact. In order to test this, the authors compared the "knowledge construction behaviour and cognitive patterns" (p. 610) of 50 college students using either an LMS or Facebook. The authors made use of quantitative content analysis to examine the interactions between students to reveal "the cognitive patterns as well as the depth of students' discussion" (p. 611). Over a period of three weeks, students were assigned a group project focusing on different aspects of computer networks in daily life. Each group was assigned either to a Facebook closed group or an online discussion forum embedded in their learning management platform. Based on the analysis of the posts and comments on both platforms, the authors argued that students engaged in more off-topic discussion on Facebook than on the discussion forum. The researchers described these off-topic interactions as a form of social interaction that may promote positive emotions during the learning activity. The analysis also showed that the students were more engaged on Facebook. The researchers justified this engagement by the fact that students are regular Facebook users and thus would check their group more regularly. This contributed to more timely responses to other students in the Facebook group compared with the online forum that the students visited less frequently. In other words, the students engaged more frequently in the project discussion on Facebook than in the discussion forum. In conclusion, Hou and his colleagues (2015) recommended incorporating Facebook in learning along with appropriate teaching strategy, emphasising that "technology itself does not trigger meaningful learning" (p. 618).

Green, Farchione, Hughes and Chan (2014) were interested in the implications of an asynchronous online discussion forum for physiotherapy students learning about anatomy. They focused on 138 students taking an anatomy class where they were prompted to complete assignments in a discussion forum. The study focused both on the final grade of the students and the content of the discussion forum. The analysis showed that the total number of posts had a positive direct effect on the final mark of the students. The researchers concluded that "posting on asynchronous online discussion fora leads to improved learning outcomes" (p. 75). An earlier study by Cheng, Paré, Collimore and Joordens (2011) reached a similar conclusion regarding the positive impact on learning outcomes of online fora. However, in another study by Green and Hughes, focusing on physiotherapy students learning about anatomy (2013), only 48 per cent of the students posted on the forum, bringing into question any genuine interest on the part of the students for this kind of platform. Cheng et al. (2011) stated that students in a psychology course, who participated voluntarily in the online forum embedded in their learning management platform, performed better in the course and slightly improved their exam performance. Yet only 11.1 per cent of the students posted at least once, reinforcing the impression that the use of online discussion fora might be mainly institution driven rather than based on the students' interests or already established online social routines.

VoiceThread

In Study IV, I analysed the questions asked of a scientist by students in an online presentation on the VoiceThread platform. This platform allows users to watch a presentation at their own pace and to navigate back and forth through the presentation, and questions could be posed anytime.

The use of VoiceThread in instructional practices has been studied in a large variety of settings, for example in early childhood teaching (e.g. Gillis, Luthin, Parette, & Blum, 2012), professional education, such as nursing (e.g. Donnelly, Kverno, Belcher, Ledebur, & Gerson, 2016; Fox, 2017), business (Chan & Pallapu, 2012) and teacher education (Kirby & Hulan, 2016).

A wide range of methods has been used to collect data when studying the inclusion of VoiceThread in instructional practices. Researchers have been collecting activity logs (Beach & O'Brien, 2015; Dugartsyrenova & Sardegna, 2016; Oh & Kim, 2016), taking field notes of VoiceThread activities (Dugartsyrenova & Sardegna, 2016), running focus groups (Beach & O'Brien, 2015), carrying out semi-structured interviews (Dugartsyrenova & Sardegna, 2016; Oh & Kim, 2016) and using responses from online questionnaires (Dugartsyrenova & Sardegna, 2016; Fox, 2017), as well as blending several sources of data in a mixed-method approach (Dugartsyrenova & Sardegna, 2016; Fox, 2017). While some researchers have been interested only in the implications of VoiceThread others have compared VoiceThread with different online text-based discussion boards (Fox, 2017; Kirby & Hulan, 2016).

Results from these studies report various positive outcomes of VoiceThread for instruction, such as promoting students' engagement (Kirby & Hulan, 2016) and enhancing their motivation and improving their understanding (Gillis et al., 2012). The VoiceThread application has also proven easy to use and to aid collaboration between students and teaching staff (Chan & Pallapu, 2012), enabling a feeling of intimacy, community and personalised discussions (Kirby & Hulan, 2016). The studies, therefore, support the idea that VoiceThread can be an effective tool for promoting learning activities. However, the most valuable aspect of VoiceThread in relation to the focus of my thesis and its sociocultural roots lies in its communication potential. Brunvand and Byrd (2011, p. 36) argued that "another benefit of VoiceThread is that it is specifically designed to promote the collaborative development of knowledge by providing students with the opportunity to share their voice, quite literally, and express opinions regardless of their ability". Educause Learning Initiative (2009) also distinguishes VoiceThread from other digital technologies based on its potential to integrate students' voices for commenting along with presenting and "defending their work before experts and peers" (p. 2). As demonstrated with younger audiences, the impact of VoiceThread on users' expressions goes beyond the writing and speaking, as students can represent their understanding of the topic taught through performance, art or other means (Gillis et al., 2012). The multimodal aspects of VoiceThread make it possible for participants to communicate their ideas, opinions and reflections in various ways. Beach and O'Brien (2015) studied 6th graders' use of VoiceThread as part of a science enquiry project on photosynthesis and carbon dioxide (CO_2) emission. The students reported that the setting enhanced the sharing of alternative perspectives, and the analysis of the students' annotations indicated that they engaged in causal reasoning regarding the relationship between photosynthesis and CO_2 emissions. Often, the benefits are argued to stem from the audio-based environment that seems to improve the sense of social presence, reminding the students that they are interacting with real people and, thus, adding a human dimension to the instructional activities (Oh & Kim, 2016;

Fox, 2017). Fox (2017) also reports on the importance of the audio and video components, which facilitate communicating emotion through nonverbal cues that can improve the understanding of the argumentation of other participants.

Kirby and Hulan (2012) indicate that an important component of the argumentative aspect of VoiceThread is linked to the waiting time. The asynchronous nature of this tool gives students time to respond, time that is not available in the flow of activities in the regular classroom (cf., Study IV).

As environmental issues are of global interest, citizens across the world need to develop some understanding of these issues. In this respect, it is important to offer possibilities to join shared discussions between peers or between peers and experts. Here English becomes the lingua franca, which can raise inclusion issues for people who are less comfortable with engaging in argumentation in a non-native language. VoiceThread, though, does offer ways to overcome these language barriers to some degree. Dugartsyrenova and Sardegna (2016) investigated the use of VoiceThread among eight Russian undergraduates. These were foreign-language learners, attending six tutoring sessions that combined face-to-face instructions with VoiceThread activities. The authors collected data through observations and activity logs, along with a survey and semi-structured oral interviews. The participants agreed that using VoiceThread increased their confidence in oral interactions and helped them develop their oral fluency. They also indicated feeling more comfortable posting audio comments on VoiceThread than speaking in class. It can be concluded that the playback and record features were important factors in the students' skills development and reflection process. Moreover, the researchers highlighted the importance of the additional time available to students due to the asynchronous nature of this tool, giving them the ability to reflect on and improve their contribution, as argued previously by Kirby and Hulan (2012). Nevertheless, in Dugartsyrenova and Sardegna's (2016) study, the students did not consider the VoiceThread interaction between participants to be as encouraging as face-to-face classroom interactions.

Digital technologies and learning about nature

An account of the use of digital technologies for the purpose of fostering ocean and environmental literacy would not be complete without discussing the potential challenges emerging in this context. As discussed in this chapter, digital technologies are regarded as potentially facilitating citizens' understanding, awareness of and ability to act responsibly in relation to current and pressing (marine) environment issues. Research has argued that connectedness to nature is central to pro-environmental behaviours and attitude (Bruni, Chance, Schultz, & Nolan, 2012; Heimlich & Ardoin, 2008; Verges & Duffy, 2010). As a consequence, there is a growing concern that the increased contact between humans and digital technologies competes with, even decreases, first-hand experiences of the natural environment (Kareiva, 2008; Louv, 2005; Pergams & Zaradic, 2006, 2008). This disconnection could prevent people from developing engagement with nature (Fletcher, 2017). Louv (2005) coined the term "nature deficit disorder" to talk about the decline in direct nature experience. He argued that the three main causes of this reduced connection with the wilderness are the loss of natural surroundings in family neighbourhoods, parental fear and the omnipresence of screens. Similarly, Pergams and Zaradic (2006, 2008) investigated the potential causes of the decreasing visits to USA national parks since 1988. They found this to be significantly correlated with the rise of electronic entertainment. There was a negative correlation between national park visits and the average hours per person spent using the Internet, playing video games and watching home movies and television. They concluded: "National Parks visits may be one casualty of a social change in values characterized by our increasing pursuit of electronic media entertainment" (Pergams & Zaradic, 2006, p. 391). They also acknowledged that correlation is not causation but defend their position by emphasising the power of their statistical analysis, combined with the fact that indoor and outdoor activities compete for our limited free time. Moreover, they stated that the emergence and growing popularity of Internet and video games matched the period when park visits started to decrease. They also recognised that other factors are to be considered and studied further, such as the increase in foreign travel that might indicate a shift in the common type of outdoor experience. Their conclusion was that "we may be seeing evidence of a fundamental shift away from people's appreciation of nature (biophilia, Wilson, 1984) to 'videophilia,' which we here define as 'the new human tendency to focus on sedentary activities involving electronic media'" (p. 393).

Paradoxically, as shown clearly in Study I, the use of digital technologies can also be used to promote understanding of and connection with the natural environment. This leads to a situation where digital technology could be seen either as a disruptive force disconnecting people from the natural world or as a new means for people to connect with the natural environment. As demonstrated here, the impact of digital technology on experiences of nature is complex. In order to understand the tensions between digital technologies and natural experience, Büscher (2016) advocated for more research in the field of digital technologies and environmental issues. This thesis envisions the use of digital technologies as a means to offer new experiences that otherwise might be impossible. However, I must stress that my work does not support the idea that virtual activities should replace first-hand experience of the natural environment, and the marine environment in particular.

4. Theoretical framework

In this chapter, I elaborate on the sociocultural perspective on learning, which is the theoretical framework adopted in this thesis. Key concepts such as situatedness of learning, cultural tools and mediation will be discussed, as well as a reflection on the key role of language in learning practices.

Learning through participation in situated practices

In this thesis, learning is seen as emerging from and embedded in peoples' participation in social practices (Lave & Wenger, 1991; Säljö, 2005; Vygotsky, 1978). This means that learning is understood in relation to the specific sociocultural context in which it occurs (Anderson, Reder, & Simon, 1996). To illustrate this idea, let us imagine two teenagers learning about the ocean. Their actions will be very different in a school situation, where specific rules and norms apply, from if they are watching a nature documentary on television at home. Moreover, these students' behaviours depend not only on the location but also on the context in which they are there. For example, teenagers visiting an aquarium with their school will engage in different actions from if they were visiting the same place during their free time. In other words, the situated nature of participation suggests that learning cannot be isolated from the context in which it happens and, as argued by Sadler (2009):

> knowing and learning are not processes that transpire independent of context and, therefore, cannot be considered as isolated events that occur in the minds of individuals. As individuals participate in environments and engage with the communities that form these environments, they begin knowing and learning. (p. 2)

According to this perspective, the way people make sense of the world is embedded in their actions in social practices (Lave & Wenger, 1991; Säljö, 2005). In this respect, the analytic focus will be not on the individual learners but on what Greeno (2006) terms the "activity systems" (p. 79), which include the participants, physical environments, institutions and the social contexts in which the learning takes place.

If we go back to the two teenagers learning about the ocean, we could observe them discussing a graph representing the change of temperature in the ocean over time. According to Vygotsky (1978), the graph can be seen as a cultural tool that mediates a form of social memory, that is it serves as an externalisation of human knowledge. The use of cultural tools such as the graph (along with language, signs, etc.) connects humans to their past and to how knowledge has been organised and accumulated in our societies. Cultural tools also invite specific ways of thinking and working. As described by Säljö (2005), "human beings' knowledge and capacities are so intimately linked to the tools they have access to, that it is impossible to differentiate competencies from the use of the tools themselves" (p. 66, my translation). Therefore, the cultural tools, also referred to as artifacts, are externalisations of human knowledge and expressions of collective learning, inviting specific ways to think and work.

Wertsch (1998, p. 53) defines appropriation as the process "of taking something that belongs to others and making it one's own". In a study of students' use of a carbon footprint calculator (CFC), Edstrand (2017) illustrates how students appropriate the concept and make use of it in their reasoning:

> The tools are loaded with conceptual constructions that are beyond the students' comprehension. However, when students make use of these tools in a context where environmental topics are on the agenda, the output value becomes a resource for their reasoning about the environmental impact of various activities. (p. 89)

In Edstrand's example, the CFC is thus an example of a cultural tool that shapes human reasoning and behaviours. Not only does it restructure the way we perceive a phenomenon, it also provides numerical values that make possible different kinds of comparisons, which would otherwise be extremely difficult and time consuming to calculate, even for experts. Consequently, this tool provides shortcuts between a given behaviour and the CF associated with it through a specific mediating tool. However, the complex calculations taking place in the CFC stay invisible to the user. This phenomenon, called black boxing, is defined by Latour (1999) as "the way scientific and technical work is made invisible by its own success" (p. 304). He argued that

> When a machine runs efficiently, when a matter of fact is settled, one need focus only on its inputs and outputs and not on its internal complexity. Thus, paradoxically, the more science and technology succeed, the more opaque and obscure they become. (p. 304)

As described in Study III, the black-box nature of a carbon footprint calculator enables users to skip tedious calculations and complex conceptual elaborations, some of which would require expertise well beyond their capacities, and, instead, obtain direct access to their carbon footprint. Black boxing allows users to manipulate and reflect on concepts that become visible and manageable to them.

In this way, cultural tools mediate the world for us. As argued by Wertsch (2002, p.105), "action and mind are fundamentally shaped by the 'cultural tools' or 'meditational means' that individuals and groups employ". Cultural tools can be seen as mediating the learning process (both in relation to what is learnt and how it is learnt), structuring our understanding of (something in) the world. Säljö, Eklund and Mäkitalo (2006) illustrate the mediated nature of cultural tools by discussing the human actions involved in multiplying a number with several digits and decimals. This action, impossible for most of us to calculate mentally, becomes accessible with the help of a pen and paper, and completely trivial with a calculator. This exemplifies the ways in which humans carry out a given activity that is deeply transformed by the cultural tools involved. Returning to our students in an aquarium, we can imagine that the way they engage with a touch tank is very different from how they would interact with a touch screen.

Language and learning

The theoretical basis of this thesis considers knowledge as developing through participation in practices and social interaction. In consequence, language is seen as the most central component of learning (Vygotsky, 1986; Wertsch, 1998; Säljö, 2000, 2005). The sociocultural perspective views language as the primary means of coordinating interaction and as a system of resources for making meaning in a given context (Lemke, 1990). Thus, our behaviour interacts with our understanding of the situation, and in all these activities language serves as a mediating resource. In Vygotsky's perspective on learning and development, language is the prime tool humans use to make sense of what happens in the world both as a way of reasoning and thinking and, at a collective level, for codifying human experiences. As "we learn to structure our own activities and the world through language" (Säljö, 2011, p. 6), learning is closely linked to communication.

Language, both written and spoken, is at the core of scientific activities, allowing scientists to formulate research questions, engage in research and negotiate and communicate their findings with peers and wider audiences (McGinn & Roth, 1999). In order to provide coming generations with skills that enable them to understand and take active part in societal scientific discussions, "talking science" (Lemke, 1990; Gyllenpalm, Wickman, & Holmgren, 2010) needs to be a central activity in school as well. Science learning requires learners to master a specialised language relevant for making meaning in the context of science. Natural sciences (as other sciences) have developed specific discourses that are important to master, at least to some extent, in order to participate productively in discussions in scientific contexts. For example, in natural sciences, "acid" refers to the pH value of a substance and provides information about its chemical composition. The same word used during a wine-tasting event would refer to a very different concept, one that concerns the quality of the wine and its taste. Understanding the semantics of "acid" as it is used in different settings is essential in order to react appropriately to the information concerning the acidity of a liquid. Without this shared meaning, the participants will not be able to work together towards a common goal. Language serves as a system of resources for making meaning in any given context (Lemke, 1990), and our behaviour is co-determined by our understanding of the situation as it is mediated by language. Being able to understand the semantics of a term in a scientific context is crucial to becoming a participant of the activity in question. In this respect, my thesis has a specific focus on the communication aspect of students' ocean literacy.

Systems thinking

A central feature of the problem I am interested in concerns the ability to develop a conceptual understanding of the marine environment and of associated issues.

To give a tangible example, driving your car in the middle of the winter to your local store to buy strawberries that have been shipped across the world will contribute to the increase in global CO_2 atmospheric concentration.

About a third of the CO_2 emitted as a result of your craving for these strawberries will be dissolved in the ocean and will contribute to increasing the level of acidity of the seawater around the world, impacting on marine life in remote places far away from your local grocery store. This example illustrates how the temporal and spatial distance between a cause and its consequences in the ocean makes the impact of any change difficult to grasp, and, as a result, to care about and act upon (Trope, Liberman, & Wakslak, 2007). In the literature, the concept of systems thinking is often used to discuss this complexity and how to address it. As described by Sterman (1994) systems thinking means:

> the ability to see the world as a complex system, in which we understand that "you can't just do one thing," that "everything is connected to everything else." If people had a holistic worldview, it is argued, they would then act in consonance with the long-term best interests of the system as a whole. Indeed, for some, the development of systems thinking is crucial for the survival of humanity. (p. 291)

In other words, systems thinking is a means of understanding and dealing with the complexity of the interplay between the different elements of a situation or a system. The concept also constitutes an ambition to make citizens able to understand relations, patterns, causes and consequences in interactions between elements of a given system. For example, WWF (2016) argues that systems thinking is essential in order to resolve the environmental problems affecting our planet as "complex problems and implementation of solutions requires a much deeper understanding of pressure, drivers, root causes and the basic dynamics of systems" (p. 89). From the Vygotskian perspective, systems thinking can be seen as a capacity that presupposes that people are familiar with scientific concepts or ways of thinking (Vygotsky, 1986). Such conceptual resources often require explicit instruction, where the connection between different concepts and cause-and-effect relationships are made clear, in order to be appropriated by individuals. Thus, and following the Vygotskian line of argument, schools, and other sites of learning, play a central role in familiarising people with such modes of thinking.

5. Research questions

As described in the previous chapters, the ocean, which we depend upon greatly, is in danger because of our lifestyles. In order to protect the marine environment, citizens need to be informed participants in the public debate about these environmental issues. In other words, they need to be ocean literate. As discussed earlier, previous research in the field of ocean literacy has pointed to the difficulties facing citizens in taking ownership of the issues related to the marine environment. This lack of familiarity with the ocean has to do with different challenges. First, despite their growing importance, marine topics are still handled very anecdotally in schools (Gotensparre et al., 2017; Hoffman, Martos, & Barstow, 2007). Second, first-hand experience of the marine environment is difficult because the ocean is often not at our doorstep in the way the terrestrial environment is. This can make it difficult for citizens to have a close connection to the ocean. Moreover, even for people living by the coast and having the opportunity to connect regularly with the ocean, most of this ecosystem is hidden under the surface or kilometres away from the coast. Finally, the ocean consists of a wide range of physical, biological, chemical and ecological processes that occur over different time and space scales. This makes it difficult for people to understand the numerous interactions taking place in the ocean and to comprehend how a given disruption here could have repercussions across time and space.

Digital technologies have the potential to overcome some of these challenges by bringing humans and the ocean closer through virtual exploration or virtual interaction with marine stakeholders and by making some of the complex interactions visible to the human eye.

Unfortunately, despite the importance of marine-related issues in our current society, very little research has been conducted in the field of marine education and even less on the implications of digital technologies for enhancing and promoting ocean literacy. In addition, the few existing studies investigating digital technologies for marine education are mainly impact studies, where some levels of competency are measured before and after a given teaching treatment. These studies focus on the knowledge outcomes in relation to ocean literacy, with little consideration given to the communication dimension or the processes through which people come to know. As a consequence, very few studies have approached marine education from a sociocultural perspective, where learning is framed as emerging from participations and interactions between actors.

My thesis aims to fill some of this gap by contributing knowledge of how digital technologies such as online discussion platforms can support communication and learning about the marine environment and its associated environmental issues. To achieve this aim, I investigate different online platforms and the associated communication that takes place in different contexts.

The following research questions have guided my research:

- How can the use of digital technologies support communication and learning of environmental skills associated with the ocean?
- What opportunities, challenges and limitations may be discerned in the use of such technologies when it comes to developing ocean literacy?
- What are the implications of ocean literacy for understanding the current environmental issues and for engaging in mitigation efforts?

6. Research methods

In this chapter, the different research methods used to analyse the empirical material of the four studies will be described and the ethical issues related to the studies will be discussed. Since the methods used in the studies differ, they will be presented study by study in this chapter. Study I is a literature review of 16 papers addressing the use of digital technologies in environmental education. In Study II, comments from a Facebook page and interviews from some active members of this page serve as a data corpus to better understand the learning opportunities emerging from this kind of Facebook page. In Study III, quantitative as well as qualitative data are used to make sense of how familiar students are with their carbon footprint and how the use of the CFC shapes their way of reasoning around this issue. Finally, Study IV offers a thematic analysis of the questions asked of a scientist by students in an asynchronous online discussion (Table 2).

Table 2. Overview of the data and methods used to address the different research questions from the four studies included in this thesis.

	Digital technologies	Research questions	Data source	Method
I	/	How has technology been used thus far in EE?	16 peer-reviewed papers	Literature review
		What impacts might technology have on teaching and learning in EE?		
II	Facebook	What learning opportunities emerge from the kind of interaction that Facebook could facilitate between citizens and scientists?	Comments on MFP stories	Discourse analysis
			Semi-structured interviews from MFP fans	
III	Carbon footprint calculator & Online discussion forum	How do students estimate their footprint and how do they compare it to the national and/or world average?	CFC	Comparisons between students' estimations of their CF and the national/global CF average.
		What kinds of reasoning about carbon emissions are observable through the use of the calculator?	Online discussion	Discourse analysis of students' posts about their experience with the CFC.
		What impact do students consider calculating their CF has on their environmental behaviour and their views on climate change?	Post-activity questionnaire	Quantitative analysis of two questions
IV	Virtual laboratory on ocean acidification & VoiceThread	What kind of reasoning can be discerned as premises for the students' questions?	Students' questions posted on VoiceThread	Thematic analysis of the questions posted by the students
		What possibilities for enhancing students' ocean literacy are made available using these kind of tool-mediated activities in instruction?		

Study I: Literature review

The first study aimed at setting the stage with respect to how much has already been studied in the field of digital technologies in environmental education (EE). In order to reach this goal, a literature review was completed. The purpose of this literature review was to present illuminating examples of how ICT has been used thus far in EE learning activities and to discuss the impacts that digital technologies might have on teaching and learning in EE.

In order to find suitable studies to include in this review, we searched the Education Resources Information Centre database, using several keywords combined (e.g. ICT, EE, environment and digital technologies). Searches were also conducted in EE and science education peer-reviewed journals, such as Environmental Education Research and Research in Science Education. Since keywords are not consistent across publications, we also used the snowball method of finding relevant articles in the references section of already found papers (Biernacki & Waldorf, 1981). Finally, the references cited in the papers already identified were reviewed to find additional articles. Only peer-reviewed articles discussing a learning activity that made use of some sort of technology were selected. Secondly, the learning activities studied in the peer-reviewed papers needed to be considered as environmental education. To qualify for this, we decided that these learning activities should fulfil at least four out of the six goals of EE outlined by the United Nations Educational, Scientific and Cultural Organization (1975, 1977):

1. Increase environmental awareness.
2. Acquire value and feeling of concern about the environment.
3. Develop skills to identify and solve environmental problems.
4. Give an opportunity to participate in environmental solutions.
5. Present an interdisciplinary aspect.
6. Include an international and local dimension.

Sixteen learning activities, investigated in nineteen studies, fulfilled at least four of these goals. Table 3 presents the sixteen activities reported in the nineteen papers selected and their alignment to the EE criteria.

Table 3. The sixteen activities reviewed in Study I listed and alignment with the six criteria. The "?" indicates that it is difficult to determine if a given activity fulfils a criterion based on the information provided in the publication(s).

#	Activity	Authors	Goals of EE						Number of criteria fulfilled
			1	2	3	4	5	6	
1	Google Earth	Guertin & Neville (2011)	✓	✓	?	?	✓	✓	4
2	Virtual field trip	Jacobson, Militello, & Baveye (2009)	✓	✓	✓	?	✓	✓	5
3	Virtual museum	Tarng et al. (2008)	✓	✓	?	?	✓	✓	4
4	E-Junior	Wrzesien & Alcañiz Raya (2010)	✓	✓	✓	?	✓		4
5	Virtual ecological pond	Tarng et al. (2010)	✓	✓	✓	?	✓		4
6	Video podcasts	Hill & Nelson (2011)	✓	✓	?	?	✓	✓	4
7	Environmental virtual field trip	Ramasundaram et al. (2005)	✓	✓	✓	?	✓		4
8	Acid Ocean Virtual Lab	Fauville et al. (2011) Petersson, Lantz- Andersson, & Säljö (2011)	✓	✓	✓	?	✓		4
9	River City	Ketelhut & Nelson (2010)	✓	✓	✓	?	✓		4
10	Quest Atlantis	Hickey et al. (2009) Lim (2008)	✓	✓	✓	✓	✓	✓	6
11	Under Control	Engstrom & Jewett (2005)	✓	✓	✓	?	✓		4
12	Appropedia	Pearce (2009)	✓	✓	✓	✓	✓	✓	6
13	Sense Project	Fraser et al. (2005)	✓	✓	✓	?	✓		4
14	Environmental detectives	Squire & Klopfer (2007) Klopfer & Squire (2008)	✓	✓	✓	?	✓		4
15	TimeLab 2100	Klopfer & Sheldon (2010)	✓	✓	✓	?	✓		4
16	Mobile phone for environmental awareness	Uzunboylu et al. (2009)	✓	✓	✓	✓	✓		5

After becoming familiar with the sixteen activities, the authors classified them according to where the learning activity took place: indoors in the classroom or museums, or outdoors during field trips.

For each of the sixteen activities, the learning activity was summarised along with the research component. The learning activity and the technology used were described in order to provide a good understanding of the setting of the study. The research associated with each activity was summarised along with the findings. We systematically looked for the research questions addressed, the context and the sample studied, and the results that, altogether, constitute what researchers know about the use of digital technology in EE.

Study II: Discourse analysis and interview

Study II explores communication between fans of the Facebook page of a renowned marine research institute – Monterey Bay Aquarium Research Institute. The rationale of Study II was twofold: The first goal was to evaluate the efficiency of different posting strategies. However, because this does not align with the focus of my thesis, this topic will not be explored further here. The second goal was to analyse the interactions taking place on the Facebook page in order to highlight the potential learning opportunities emerging from these interactions. To reach this second goal, it was considered appropriate to use a discourse analysis on the comments from the MBARI Facebook page (MFP). In addition, to get a richer understanding of the context in which these comments were posted, it was decided to interview some of the active members of the Facebook page.

We analysed the comments posted on the MFP stories (either on the MFP itself or shared by the MFP fans) between June 2012 and November 2012. We analysed the comments by means of discourse analysis, which is an approach for investigating the construction of individual and social norms, as well as the negotiation of social interaction through spoken and/or written language (Starks & Trinidad, 2007). Gee (2010) argued that discourse analysis is the study of language in use and is characterised by two main approaches. The first one looks at the content of the discourse, the themes used and the issues discussed, while the second approach focuses mainly on the structure of the language, such as turn-taking patterns, grammar and other features. By applying Gee's first approach (2010), and looking at the content of the comments posted on the MFP stories, we explored how fans participated in, developed an understanding of and took an interest in marine science on this Facebook page. Second, we conducted eight semi-structured interviews with MFP fans in order to obtain their view on the kinds of social interactions taking place on MFP, and analysed their answers through discourse analysis[13]. Since we were interested in discussing the potential interaction between MBARI and its fans, we contacted the MFP active fans (liking, sharing or posting at least once on MFP during the period June–November 2012), whose privacy settings allowed us to get in touch with them. A total of 108

[13] The interview consisted of questions such as "Tell me about your use of the MBARI Facebook page (how often do you comment, share, like, post?)" and "What do you think about MBARI fans' interaction with each other and with the MBARI administrator?".

fans were contacted. Eight MFP active fans accepted to be interviewed. Six interviews were conducted on Facebook chat and two were conducted via a questionnaire in a Word document. In total, three women and five men were interviewed. Four respondents were from the USA and the others were from Spain, Germany, Belgium and Sweden. One interview was conducted in French while the others were conducted in English.

Study III: Quantitative and discourse analyses

Study III analyses an I2I learning activity called the International Student Carbon Footprint Challenge (ISCFC[14]) taking place in high schools in various countries. The goal of the ISCFC is to support high school students around the world in understanding their personal impact on climate change and in envisioning local and global solutions while communicating online with students from many different countries. In this activity, the students first used a CFC before engaging in online discussion concerning their carbon footprint.

Question 1: How aware are students of their carbon footprint?

The first objective was to acquire an understanding of how much students in general seem to know about their carbon footprint. The empirical materials used to assess this came from 5,970 students. For each of them, the empirical materials consisted of:

- answers to the two introductory questions ("Do you think that your personal CF is likely to be lower, higher, or about the same as the average resident in your country?" and "Do you think that your personal CF is likely to be lower, higher, or about the same as the average human?"),
- the average national CF (CF_{local}), and
- the user's CF measured by the CFC (CF_{user}).

Two indexes were then calculated:

1. The relative CF compared to the average CF in their country: RCF_{local} (in per cent) = $[(CF_{user} - CF_{local})/CF_{local}] \times 100$
2. The relative CF compared to the average CF in the world (3,791 kg CO_2): RCF_{world} (in per cent) = $[(CF_{user} - 3{,}791)/3{,}791] \times 100$

[14] http://web.stanford.edu/group/inquiry2insight/cgi-bin/i2sea-r2a/i2s.php?page=calculate

If the RCF was higher than 10 per cent, the user footprint was considered above average; if the RCF was lower than -10 per cent, the user footprint was considered lower than the average; and if the RCF was between -10 per cent and 10 per cent, the CF was considered average.

We decided to omit the users who gave contradictory answers to the two introductory questions. For example, a Norwegian user was asked to estimate his CF in comparison to the national and world averages, with which he was supplied – national average (Norway) 7,901 kg and world average 3,791 kg. Of the two estimates he provided for his CF, one was higher than the national average (higher than 7,901 kg) and the other lower than the world average (lower than 3,791 kg). Therefore, since the user's CF cannot be both higher than 7,901 kg and lower than 3,791 kg, his two estimations contradicted each other. We omitted data from 3,352 in total who gave contradictory answers. An additional 120 users were omitted because their calculated CF was unrealistically high (above 100,000 kg). The remaining database consisted of data from 2,498 students from 80 countries. However, only a few users represented each country and the material did not have enough power for a quantitative analysis between countries. We therefore decided to focus on the users located in European countries represented by more than 10 users, and in the USA. The final database includes 1,722 users from the USA and 248 users from seven European countries (France, Germany, Greece, Italy, Sweden, Switzerland and the United Kingdom).

Question 2: What reasoning do students engage in through the use of the carbon footprint calculator?

The second objective was to get a deeper understanding of the kind of reasoning the student would be able to engage in through the use of the CFC. In order to meet this objective, the content of an online discussion was used as empirical material. The data, from a November 2011 session, were gathered from a discussion where students were asked "Did you use the calculator to identify areas in your life where you can make changes in order to reduce your footprint? Are you willing to make those changes?". Since our aim was to obtain an understanding of how each student individually experienced the calculation of their CF, we focused only on the posts where the students accounted for their experience. We did not include the students' comments to others' posts in our empirical material. We ended up with 28 posts from students located in six different countries (USA, Croatia, Switzerland, Iceland, Bulgaria and Greece). The contents of these posts were logged and anonymised while retaining the information concerning the country of origin.

Question 3: What impact do students consider calculating their carbon footprint has on their environmental behaviour and their views on climate change?

Finally, we investigated how the students considered this learning activity in terms of changing their views on climate change. All participating students filled in a survey at the end of the International Student Carbon Footprint Challenge (ISCFC), and the answers from two of the questions was used as empirical material:

- How serious an environmental problem did you consider climate change before and after participating in the ISCFC? (not at all serious; a little serious; somewhat serious; extremely serious).
- After participating in the ISCFC, are you more likely to take steps to reduce your CF? (yes, much more likely; yes, a bit more likely; no change; no, less likely; no, much less likely; no concern about footprint).

The answers from 783 students who took the questionnaire after the September 2012, November 2012, February 2013 and October 2013 ISCFC sessions were collected.

Study IV: Thematic analysis

In this last study, the aim was to get a deeper understanding of how an online scientific presentation and an asynchronous discussion with a scientist, taking place on VoiceThread, could potentially promote students' ocean literacy. This was investigated by focusing on the kind of reasoning the students engaged in, in relation to the issue of OA. The questions formulated by the students were used as empirical material.

The analysis of the questions was based on thematic analysis, a method identifying and reporting patterns or themes salient in a data corpus (Attride-Stirling, 2001; Braun & Clarke, 2006). The analysis focused on the data corpus consisting of 74 questions formulated by the students (17 questions from the classes in Illinois and 57 questions from the class in California). A complete transcript of the VoiceThread of each class was created. For each of them, the initial talk of the scientist and the students' questions and scientist's replies, were logged on a Word document. The students' questions were numbered according to their position in the VoiceThread.

As described by Attride-Stirling (2001), the thematic analysis began with an immersion in the data corpus through repeated reading, looking for patterns related to forms of reasoning displayed in the students' questions. After becoming familiar with the data, an initial coding (e.g. science of OA and solution to OA) was created by highlighting the significant feature of the questions. The codes were then sorted under potential themes by looking at ways in which to combine them. Finally, the questions were analysed and interpreted in accordance with these emerging themes. To ensure that relevant interpretations of the data were made, the thematic analysis was discussed and critiqued in different research group settings.

Research ethics

The research adheres to the ethical code of the Swedish Research Council (Vetenskapsrådet, 2011). This thesis is part of the Learning and Media Technology Studio (LETStudio) and the Linnaeus Centre for Research on Learning, Interaction and Mediated Communication in Contemporary Society (LinCS) at the University of Gothenburg, which will own all the data collected during this work.

Study I does not raise any ethical issues as the data gathered were already published in a peer-reviewed journal.

As the three following studies take place online, it is important to remember that ethics in Internet research is a young field, with the first publication[15] addressing this issue only appearing in 2002 (Markham & Buchanan, 2012). The novelty of the field, along with the constant and rapid mutation of the digital technologies available, leads to a grey area in the ethical decisions made by the researchers (Ess, 2015; Markham & Buchanan, 2012). It leaves the researchers with guidelines rather than rules and with their own responsibility for taking decisions while bearing in mind the context of their specific research project (Markham & Buchanan, 2012).

[15] Association of International Researchers Ethical Decision-Making document

In Study II, the data were collected from a public Facebook page where the content was logged and anonymised in order to protect the privacy of the participants and their Facebook friends (Ess, 2015). The persons interviewed were informed about the study and it was agreed that they could choose to end the interview at any point. The participants in the interviews were anonymised.

For studies III and IV, all participants were informed about the I2I project and its research component. They were informed of the purpose of the study and that the data would be anonymised.

In Study III, the data were collected from an online discussion forum (Einztein[16]), the CFC and the survey distributed at the end of the activity. The discussion investigated in the online discussion forum was public and thus visible to all users and I2I staff members, including the I2I researchers. To respect their anonymity, we changed the names of the users. We did not, though, change their country of location because this was an important element of the study. Furthermore, the students answered anonymously to the questionnaire after participating in the ISCFC.

In Study IV, the teachers informed their students about the research dimension of the learning activity and they were asked for their agreement to take part. While participating in the online lecture with the scientist, students needed to create a personal account. They used nicknames as identification in order to stay anonymous. In publishing the study, these nicknames were not used, to assure complete anonymity. This study was also conducted in accordance with guidelines established by the Association of Internet Researchers (Markham & Buchanan, 2012).

Studies III and IV can be regarded as naturalistic as the researchers were not the initiators of this learning activity. The teachers decided independently to implement these learning activities as part of their regular teaching practices. Moreover, no financial compensation was offered to them, as is sometimes customary in USA culture.

[16] Einztein was the social learning network used at the time of the data collection to host the ISCFC discussion between students. Einztein was closed down in February 2014 for economic reasons. The online discussion forum now used for the ISCFC discussions is hosted on Muut.

7. Summary of the studies

The goal of the four studies is to increase our understanding of the role and potential of digital technologies, including communicative activities mediated by social media, for supporting learning about environmental issues. A better understanding how such tools may support learning in these multidisciplinary and complex areas can lead to a more ocean-literate population that is better prepared to address some of the new challenges of the Anthropocene. An overview of each of the four studies will be provided in this chapter.

Study I: ICT tools in environmental education: Reviewing two newcomers to schools

Published as:
Fauville, G., Lantz-Andersson, A., and Säljö, R. (2013). ICT tools in environmental education: Reviewing two newcomers to schools. *Environmental Education Research, 20*(2): 248–283.

This study is a literature review of the use of digital technologies in environmental education (EE). Environmental education plays an important role in preparing citizens to be accountable for the consequences of their lifestyle on the health of the planet. Highlighted by Stevenson (2007, p. 146), "[t]eaching and learning [EE] are intended to be co-operative processes of inquiry into and action on real environmental issues", that is students should be put in the position of active thinkers, prepared to act in response to multidisciplinary and controversial issues in collaboration with fellow students.

Thus, the pedagogy and philosophy behind EE can be regarded as something of a challenge to traditional approaches to instruction, which tend to focus on the acquisition of factual and accepted knowledge presented in the classroom by the teacher in order to solve problems with an already existing, single and correct solution (cf. Sfard, 1998). A characteristic of traditional curricula is also an organisation of information and knowledge, which is often rather fragmented and structured in terms of a tradition of disciplines and sub-disciplines. This tradition risks putting students in a rather passive position, where a large proportion of the teaching simply reproduces information, established knowledge and standard procedures (Stevenson, 2007).

EE is not the only newcomer exerting pressure on established teaching habits and disciplinary structures. The implementation of digital technologies also challenges current educational practices. Students now have easy access to vast sources of information that complement, but also sometimes challenge, traditional media such as textbooks. For education, access to up-to-date knowledge and information is vital, but still such resources compete with many features of the established patterns of teaching and learning, where the text book has played, and continues to play, a central role. So even if technology in education is not new, it is developing at a rapid pace, with consequences for learning and instruction. As the use of technologies provides many learning opportunities that are different from the traditional text-based teaching, we are likely to see many changes in the ways we organise teaching and learning (Säljö, 2010).

EE and digital technologies can be regarded as relative newcomers in the context of schooling and both share the potential to support critical and action-orientated problem-based instructional practices. Moreover, as ICT tools and EE both allow for innovation in the education field, EE seems a promising setting in which to integrate such tools. Combining these two newcomers is a new field with relatively little research addressing it and with a lack of systematic ways to explore its impact on learning.

The purpose of this literature review is to present illuminating examples of how digital technologies have been used thus far in EE learning activities and to discuss the impacts that digital tools might have on teaching and learning in EE.

To find research studies, we conducted a systematic review of the literature along with a snowball approach to source additional papers. To determine what articles to include in the review, we decided that they needed to fulfil four of the six criteria identified in the definition of EE by UNESCO (1975, 1977):

1. Increase environmental awareness.
2. Acquire value and feeling of concern about the environment.
3. Develop skills to identify and solve environmental problems.
4. Give an opportunity to participate in environmental solutions.
5. Present an interdisciplinary aspect.

6. Include an international and local dimension.

Nineteen studies covering 16 learning activities were selected to be included in the literature review. The studies covered several types of technologies (e.g. handheld devices, computers and mobile phones) used in instructional settings ranging from primary to university education and from outdoor trips to indoor adventures. For each study, a summary of the instructional setting and the research findings was formulated. Table 4 provides a brief overview of the 19 studies (Table 4).

Table 4. Overview of the 19 studies included in Study I. The number (#) corresponds to the number given to each learning activity in Table 3 (page 70).

#	Topic taught	Research subject	Research method	Findings
1	History & contexts of oil spills	Middle school students	n/a	n/a
2	Soil degradation linked to human civilizations	15 undergraduate & undetermined number of students from another class	Multiple-choice questionnaire evaluating recall of the content	Very high % of correct answers
3	Marine ecology	Six 5th & 6th graders, three teachers	Interviews & Observations	Students engaged. Benefits & challenges for teachers
4	Ecology, natural Science	48 students (10–11 years old)	Tech vs traditional learning. Pre- & post-tests, observation	Increase in knowledge with both treatments
5	Natural and environmental science	2nd grade, three classes	Tech vs traditional learning. Pre- & post-tests, interviews	Increased memorisation & comprehension with both treatments. Critical thinking higher with tech
6	Biogeography & conservation	Undetermined numbers of undergraduate students	Questionnaires, focus group. Assessment results with and without podcasts	No difference in average grades. Students more engaged with their learning with podcasts
7	Properties of specific landscapes	n/a	n/a	n/a

Table 4. (*Continued*).

#	Topic taught	Research subject	Research method	Findings
8	Ocean acidification	30 high school students	Pre- & post-tests	Increase in knowledge
8	Ocean acidification	80 high school students	Pre- & post-assignment	Indication of transfer of knowledge
9	Environment and human health	Five teachers & 500 7th graders	Tech vs traditional learning. Pre- & post-tests	Increase in knowledge in both treatments. Higher engagement in tech
10	Culture, ecology, maths, English	Four classes of 6th graders	Tech vs traditional learning. Questionnaire	Increase in knowledge slightly higher in tech treatment
10	Culture, ecology, maths	80 students in primary school	Observations, pre- & post-tests, interviews	Increase in motivation
11	Impact of damming the Missouri River	Middle school students	n/a	n/a
12	Physics of energy & the environment	Distant learners in higher education	n/a	n/a
13	Air pollution	One class of 10–11-year-olds and one class of 13–14- year-olds	n/a	n/a
14	Environmental engineering	Three university classes, one high school	Naturalistic case study methodology	Opportunities for complex problem solving. Importance of scaffolding
14	Environmental engineering	Four university classes	Iterative design, observations, video recording	Enthusiasm but failed to reach the learning goal
15	Political implications of environment.	Undetermined number of students	Observations	Connection between scenario & personal experience
16	Local environmental awareness	41 university students	Pre- & post-tests	Increase environmental awareness

To summarise, the literature review reveals that there are rich varieties of technology-based educational resources available for EE. However, there is far less research available that examines what these tools imply for students' activities and for learning and instruction. The focus of the studies is far more often to develop digital resources and integrate them into learning activities than to investigate what it means to learn environmental issues mediated by the use of technology, and what it implies for the students' possibilities to develop environmental literacy. This problem of the foci of studies is not unique to EE and technology and has been observed in several other fields of education (e.g. Arnseth & Ludvigsen, 2006; Fauville, Säljö, & Dupont, 2013).

A common result in the reviewed studies is that the outcomes produced when using technology-based instructions in EE either show a lack of significant effects on student learning and/or attitudes, or they show a slightly positive result in terms of certain outcome measures. Some studies also aimed at comparing the learning outcome of a traditional learning context versus a context where digital technology was embedded. The research has made use of different methods (observation, pre- and post-tests, interviews and knowledge questionnaires). This diversity, combined with the rather unclear results, makes it difficult to draw conclusions at a general level.

It is also important to remember that the digital technology to be tested is often implemented in the teachers' curriculum only for the sake of the evaluation itself. Thus, this field of research largely consists of examining arranged situations, experimental environments and short-term interventions. Extra resources, such as experienced research staff and recent digital applications, also form part of such studies. When these extra resources are no longer there, a different picture of the activity often emerges, which makes it hard to determine what the research says about regular teaching and learning. This is also likely to be the reason why the results of such studies are often hard to replicate (e.g. Schrum et al., 2005; Arnseth & Ludvigsen, 2006).

This review presents a range of positive impacts of the use of technology in EE, such as triggering critical thinking (Jacobson, Militello, & Baveye, 2009; Tarng et al., 2010), increasing learning interest (Tarng et al., 2008) and increasing environmental awareness (Uzunboylu, Cavus, & Ercag, 2009). Nevertheless, digital technologies can also bring additional challenges for teachers and students. For example, a lack of technical support could result in teachers wasting time trying to fix technological problem without the proper training to do so (Tarng et al., 2008). Another challenge presented is the entertainment dimension overshadowing the instructional aspect of the use of digital technology, where students seem to focus more on having fun than learning (Wrzesien & Alcañiz Raya, 2010). Another potential component of the challenges associated with technology in EE is the so-called alienation from nature (Shultis, 2001). As EE is strongly associated with the direct observation of natural phenomena in the field, the use of computers could be seen as inhibiting such an experience. This alienation hypothesis would appear to be supported by students' response to using the virtual ecological pond (VEP) (Tarng et al., 2010), with most feeling that learning in this medium was more interesting and convenient than learning from a real pond.

A conclusion of the review is that through the implementation of technology-based instructions in EE practice, students have access to a new range of experiences and fields of investigation that were not previously available. We are currently witnessing a rapid and promising blooming of digital technologies in EE, but it is one that will need time to grow harmoniously. There is also an urgent need for naturalistic studies that will provide models for productive teaching and learning. The three following studies making up my thesis take on this challenge. They investigate the possibilities for teaching and learning about marine environmental education on three technology-based platforms, inside and outside of school. These studies are naturalistic in the sense that the research was conducted on already established activities implemented for the sake of the learners rather than dictated by researchers for the purpose of a given study.

Study II: Can Facebook be used to increase scientific literacy? A case study of the Monterey Bay Aquarium Research Institute Facebook page and ocean literacy

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Knowledge of marine science is a key component of ocean literacy and is mainly held by marine scientists. In order to promote an ocean-literate society, citizens need to have access to central elements of this knowledge from the scientists themselves. Recently, the Internet in general, and social networking sites (SNSs) in particular, have become key resources for learning, sharing knowledge and communicating with others.

Scientific institutions, increasingly aware of their duty to make their research accessible to the public, are developing their engagement in such arenas to inform and engage in dialogue with the public. Facebook, as one of the largest SNSs (Facebook, 2013), offers promising opportunities for the public and scientists to be in contact and foster communication around marine issues.

Study II investigates the participation of, and interaction between, users of the Facebook page of the Monterey Bay Aquarium Research Institute (MBARI, California). MBARI is a marine institute that specialises in the innovation of technology for exploring the ocean. It also has a strong interest in disseminating the information and technology derived from its research to the public at large. This marine research institute considers that the diffusion of information must be done in ways that engage public interest in ocean science and stimulate their imagination about the future of oceanographic scientific discovery and the importance of ocean conservation. To fulfil its educational ambitions, MBARI makes use of eye-catching underwater images and videos that hold the potential to trigger discussion, interest, reflection and amazement among the public, such as this image of the barreleye fish (*Macropinna microstoma*) (Figure 4) with its transparent head.

Figure 4. *Macropinna microstoma* (vernacular name: barreleye fish) with its transparent head, observed by MBARI's scientists. © *2004 MBARI*

MBARI created its Facebook page (MBARI Facebook Page: MFP) in February 2011 and, at the time of the data collection (summer 2012), the page counted about 2,000 fans[17].

[17] As a point of comparison, in October 2017, MFP had over 38,000 fans.

In order to help readers understand the context of this study, I will provide a description of Facebook. Let's take the example of John, a new Facebook user. John starts by signing in and creating his personal profile. He can search for his real-life friends, acquaintances or family members and send them requests to become his Facebook friend. John can also follow pages created by different organisations and in so doing become a Facebook fan of these organisations. John can post stories that will be visible to his Facebook friends. A story can be a text standing on its own, or it can include different media, such as video, a link to another website, or pictures. John can interact with the stories of his friends or of the organisations he follows through several actions, such as commenting on, sharing or liking the stories he wants to react to. He can also send private messages to one or several of his friends or directly post video, photo or text on his friends or organisations' Facebook timeline (see below for description).

There are two main environments on Facebook. The first is the timeline of a person or an organisation, where all of the activities of this person or organisation are displayed, such as uploaded photos, stories posted or stories posted by friends directly on the user's timeline. The second important environment is the news feed, where the stories of the user's friends and organisations are displayed. John will find the news feed column in the centre of the main page (Figure 5).

Figure 5. Screenshot of the user's main page with the news feed displayed in the central part. Also, the ticker column, which is explained below, can be seen on the right-hand side.

When John signs in on Facebook, the main page opens and the news feed displays stories from his friends and from the organisations that he follows. Facebook chooses the stories that it presents in the news feed by using an algorithm that assigns a value to all John's friends' stories and then displays the ones with the highest values. Although the original ranking system created by Facebook to assess the value of each story, called Edgerank, has been replaced by a much more complex algorithm, the basic factors remain. In 2012, Falls described the three factors determining the value of each story according to the algorithm then in use (Edgerank). Let's investigate these factors in the context of a story posted by Jane, one of John's friends on Facebook:

1. The affinity between John and Jane on Facebook: the more John and Jane comment, like or share each other's posts, the higher their affinity is on Facebook.
2. The value of the content as determined by the number of actions (comments, shares, likes) Jane's story has already triggered. Each type of action influences, more or less, the Edgerank. For example, Facebook ranks a comment or a share as more important than a like.
3. The age of each story when the user signs in. Jane's story will have a higher Edgerank if her story has been recently posted when John signs in on Facebook.

The ticker column displays in real time the activities of John's friends, such as liking their own friends' stories, commenting on or sharing them. For example, if Jane likes a story posted by an organisation she is following, but John does not, he will still be able to see that she has liked the story, in the tinker column. He is then a click away from seeing this story from an organisation of which he is not a fan.

The main goal of the stories posted on Facebook is to reach as many people as possible; this is known as the "reach" of a story. There are two kinds of reach:

1. The organic reach, which takes place when, for example, the story posted by an organisation is seen by one of its fans, such as John.
2. The viral reach, which happens when a story is seen by a user through an action taken by one of his/her friends. For example, Jane, who is not a fan of an organisation called ABC, has seen on the tinker column that John, an ABC fan on Facebook, has interacted with an ABC story. If Jane wants to know more about what John has just reacted to, she will click on the tinker column and the story from the ABC organisation will become visible to her, thus reaching her virally.

This study investigated two different aspects of the use of Facebook by MBARI. The first part was a quantitative analysis of a series of parameters linked to each story posted on MFP before and after the implementation of a new strategy in order to test its efficacity. This first part is not described here, as it does not align with the focus of my thesis. The second part is more in line with the focus of my thesis and my interest in how the MFP could contribute to the development of citizens' ocean literacy as it focuses on what it means to be in contact with an MFP story in terms of learning opportunities. As this study is rooted in a socio-cultural perspective on learning, we investigated the interactions between the different actors of MFP in order to get a better understanding of the opportunities for learning in the context of Facebook.

We used discourse analysis to look at the content of the comments posted by the users on MFP. Discourse analysis is an approach for investigating the construction of individual and social norms, as well as the negotiation of social interaction through spoken or written language (Starks & Trinidad, 2007). We also contacted 108 active MFP fans (e.g. those who had recently liked, commented on, or shared some MFP stories) in order to conduct semi-structured interviews. The aim of the interviews was to grasp the views of the fans on the kind of social interactions taking place on the MFP. We conducted eight semi-structured interviews with fans from the USA, France, Sweden, Germany, Spain and Belgium. Six interviews were conducted on Facebook chat, while two were conducted via questionnaire in a Word document.

The interactions between MFP fans and the MFP administrators take place mainly in the comments section, offering the fans a potential arena to debate and discuss the MFP stories with more knowledgeable people (i.e. the MFP administrators). The study findings revealed that the interactions remain fairly simple, with a typical pattern being the fans asking questions and the MFP administrator replying to these questions.

Discussions between the MFP fans were found to be rare. For example, where a photo of a marine organism was posted to challenge the fans to identify the species, the MFP fans gave their own opinion as a direct answer to the challenge but did not interact with each other through argumentation in order to come to an agreement about the correct answer. The interactions between fans themselves, or between fans and the administrator, remained very sporadic despite the fact that Facebook offers features enabling interaction. This situation shifted when an MFP story was shared by a fan and made visible to his/her friends, regardless of whether or not they were MFP fans themselves. The fan's friends viewing this story would then like it, comment on it or share it with their own friends. These shared stories seem to trigger a more fertile social context for discussion. Although the privacy settings limited the amount of shared stories to which we had access, some were still accessible. These shared stories presented a level of discussion rarely observed on the MFP between fans who did not know one other. For example, an MFP fan who shared a photo of a fish was, in the absence of input from the MFP administrator, responsible for answering a question raised by one of the Facebook page friends. So, the MFP fan engaged in this discussion by searching for further information online and sharing it with the friends.

This study suggests that the Facebook page of an organisation might not be a suitable space for communication between the different actors, rather it is the sharing of stories from this page that seems to offer opportunities to trigger participation. This study should be seen as an example of a larger problem concerning the relationship between researchers and the public and how scientists can help support citizens' increased scientific and ocean literacies.

While social media aim at facilitating communication between users, it cannot be taken for granted that users will interact with each other solely because of the availability of collaborative features. As expressed by Kreijns, Kirschner, and Jochems (2003), in order to trigger social interaction "availability of communication media is necessary, but not sufficient" (Kreijns et al., 2003, p. 341). This echoes the findings of this study that show a weak level of interaction between the different actors present on the MFP.

Study III: The carbon footprint as a mediating tool in students' online reasoning about climate change

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Climate change is a complex and pressing issue that needs to be addressed through relevant knowledge mastered by citizens in order for them to be involved in its mitigation. The younger generation has been pinpointed as a key mitigation agent (Anderson, 2013) and educational contributions are seen as important in providing students with a more informed and critical view of their own lifestyles and consumption patterns. In order to engage with climate change, students need to gain an understanding of their own carbon footprint (CF) by becoming aware of the impact their lifestyle has on the environment.

While climate change is an abstract concept invisible to the human eye, tools such as CFCs have radically changed the way we can access this environmental issue, visualise our own emissions and compare them to those of others. As described by Kenny and Gray (2009):

> The calculation of individual and household CFs is a powerful tool enabling individuals to quantify their own carbon dioxide emissions and link these to activities and behaviour. Such models play an important role in educating

> the public in the management and reduction of carbon dioxide emissions through self-assessment and determination. (pp. 1–2)

CFCs are common online and easy to use. The calculator first presents a series of questions concerning the user's lifestyle (e.g. transportation habits, energy and consumption). In answering these questions, users both observe and report on their concrete everyday activities, which over time make up what we refer to as our lifestyle. The self-reported figures are combined, and the calculator then provides a total carbon dioxide (CO_2) output in kilogrammes – the user's CF.

Study III scrutinises an I2I learning activity called the International Student Carbon Footprint Challenge (ISCFC[18]) taking place in high schools in various countries. The goal of the International Student Carbon Footprint Challenge (ISCFC) is to help high school students around the world understand their personal impact on climate change and envision local and global solutions through communicating online with students from many different countries. The ISCFC is organised in sessions of about two to three weeks every four months to maximise the number of students interacting online during that period. This learning activity is divided into different steps, making use of different technologies, described in detail below. The students first use a CFC, then address mitigation on the online discussion forum Einztein and, finally, answer a questionnaire (described in detail later in this chapter).

The I2I CFC combines fifty questions addressing four main areas (transport, home energy, food and personal purchases). The questions aim at supporting students in their estimated account of their behaviour that will serve as the basis for the calculation. The questions focus mainly on daily decisions that students make themselves. The specific calculator used here includes location-specific calibrations for energy sources, agricultural practices and global climatic conditions, making it accurate for users around the world. The calculations run by the programme are extensively documented for each of the fifty questions, making it scientifically transparent. This tool also includes the ability for users to register, which is a very valuable feature both for the researchers and for the users themselves. First, the users' data are saved and can be consulted for research purposes. Second, the registered students can complete the calculator over several visits and can also update

[18] http://web.stanford.edu/group/inquiry2insight/cgi-bin/i2sea-r2a/i2s.php?page=calculate

their calculations, along with any lifestyle changes they have made, in order to test how different types of lifestyle will affect the calculated CF.

A chronological description of the calculator follows: First, the users register and select their location in order for the calculator to provide accurate calculations/outputs. After registering and choosing a location, the students discover what the average CF is for their own location (17,807 kg of CO_2 per year in the USA) and worldwide (3,791 kg of CO_2 per year) (see Figure 6[19]). They are then asked to answer two introductory questions, where they estimate if their CF is lower, about the same or higher than the average for their location and worldwide (Figure 6).

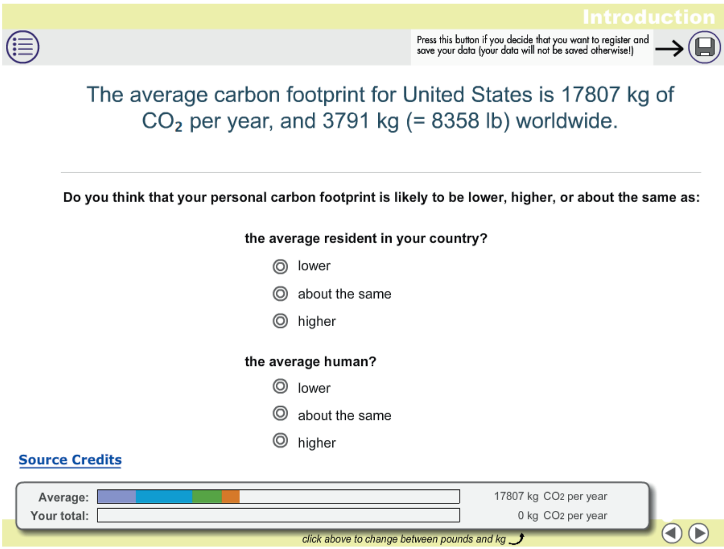

Figure 6. Introductory questions where users are prompted to estimate if their CF is lower, about the same or higher than the average for their location (in this case USA) and worldwide.

[19] The screenshots of the CFC are from the version that was used in Study III. The CFC recently underwent a redesign. The functionalities are similar but the look has been improved.

Having answered the introductory questions (answers are saved for research purposes), the students answer 50 questions concerning their lifestyle. They answer these questions by self reporting on their own behaviour. As the students proceed through the CFC, the accumulating total is displayed at the bottom of the screen in the "Your total" bar, where four colours represent the four categories of questions (transportation in purple, home in blue, food in green and purchases in orange). The "Average" bar (divided into the same four colours) provides the average CF per category in the region selected by the user (Figure 7).

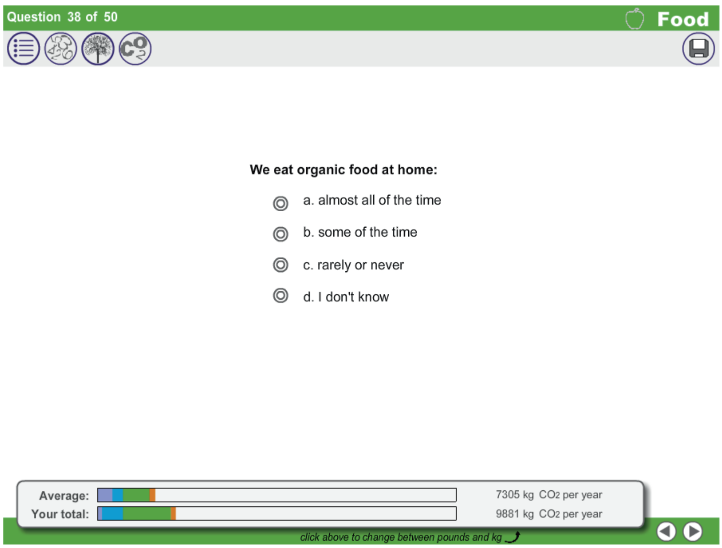

Figure 7. Example of a question addressing the consumption of organic food.

While answering a question, the students can see the increase in their CF in the "Your total" bar, providing direct feedback about the environmental impact of any given behaviour (Figure 8). In this way, the students are provided with information that directly displays the relation of a particular behaviour to the associated CF.

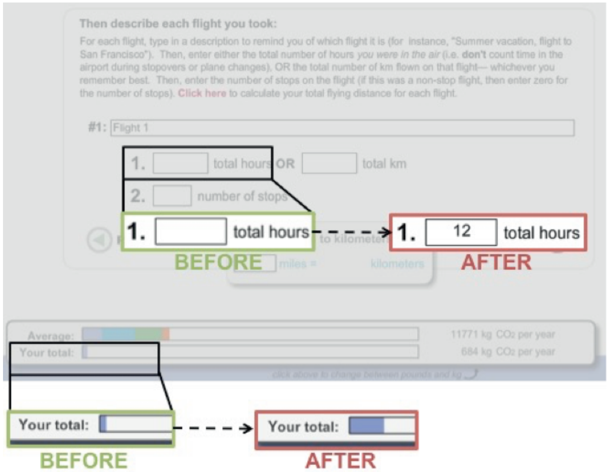

Figure 8. Illustration of how the "Your total" bar of the user is updated directly when the user is typing his/her answer to a given question, allowing direct feedback.

At the end of the 50 questions, the student's CF is displayed and compared to the worldwide and national average (Figure 9). The students are then challenged to think about how to modify their behaviour in order to decrease their CF.

Based on your input, your total footprint is 9882 kg of CO_2 per year, compared to an average of 7305 kg for Sweden, and 3791 kg (= 8358 lb) worldwide.
By category, your totals are:

	You:	Your region:
Transportation:	564 kg	1894 kg
Home:	2647 kg	1307 kg
Food:	6068 kg	3363 kg
Purchases:	603 kg	741 kg

Figure 9. The comparison between the CF of the user and the average CF for the location selected (e.g. Sweden) and the world.

After the students have calculated their CFs, the teachers gather the data together and send them to the I2I team, who post the average of each class participating on a Google map[20]. This map can then be used in the classroom to compare and discuss the CFs from students globally. Students then register on the online discussion forum Einztein to communicate with peers around

[20] http://web.stanford.edu/group/inquiry2insight/cgi-bin/i2sea-r2a/i2s.php?page=compare

the world. Various discussions[21] are created by the I2I staff, the teachers or the students themselves, relating to different aspects of climate change (e.g. mitigation, adaptation, impact and associated environmental issues; see Figure 10).

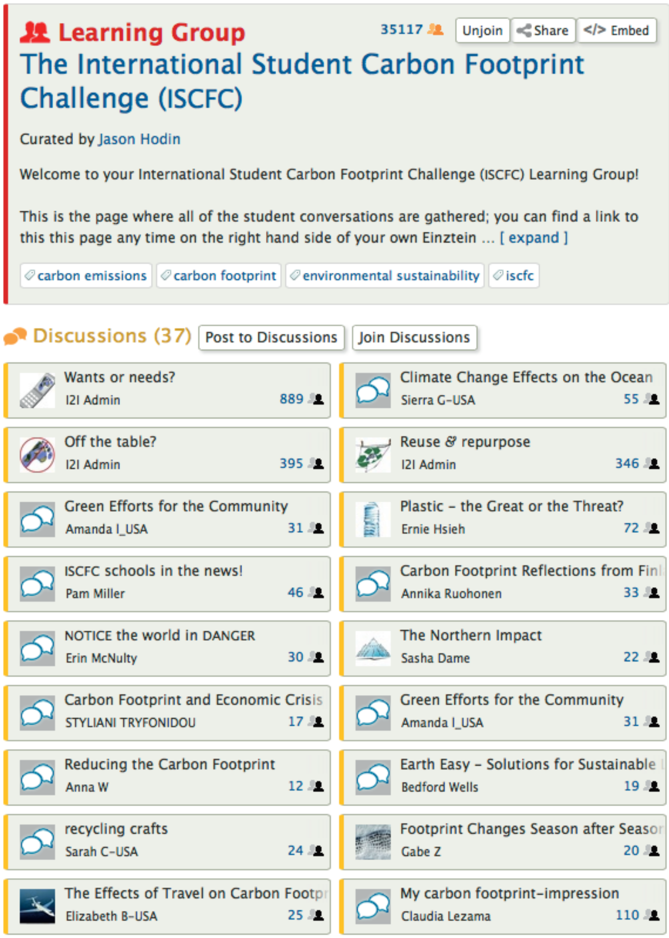

Figure 10. Screenshot presenting the ISCFC page on Einztein, with a list of the discussions students could engage in. For example, the second discussion, called "Off the table?", concerns what the students are not willing to change in their life style for the sake of the environment.

[21] http://web.stanford.edu/group/inquiry2insight/cgi-bin/i2sea-r2b/i2s.php?page=discuss

In these online discussions, the students can write a post, which is a direct reply to the topic of the discussion, or write a comment that is a reply to a specific post (Figure 11).

Figure 11. The structure of the online discussions on Einztein. The "Discussion" contains a description of the topic of these discussions. The "post" is a direct answer from a student to the topic of the discussion. The "Comments" are specific replies to a given post.

After the end of each ISCFC session, the participating students are prompted to answer an anonymous questionnaire to report on their experience with this activity.

In Study III, we explore how such a tool may sensitise young people to these issues and support more sophisticated modes of reasoning about climate change. The study focuses on the following research questions:

- How do students estimate their footprint and how do they compare it to the national or world average?
- What kinds of reasoning about CF are observable through the use of the CFC?

- What impact do students consider that calculating their CF has on their environmental behaviour and their views on climate change?

These questions are addressed analytically by adopting a sociocultural perspective on learning (Vygotsky, 1978; Wertsch, 1998; Säljö, 2005), focusing on the use of cultural tools as resources for interacting with the world. In this perspective, cultural tools, such as CFCs, are seen as directed towards mastering mental processes and co-determining how we think and behave. The tools serve as instruments of thinking and make it possible for us to reason in a sophisticated manner without necessarily understanding all the inherent processes of the tool (Vygotsky, 1997).

Each research question was addressed with different data sources (see Table 5).

Table 5. Overview of the different data collected in this study.

Data from	Details
CFC	Comparison between CF claimed by users and CF calculated by the CFC in relation to the national and global CF average.
Online discussion	Analysis of students' posts about their experience with the CFC.
Post-activity questionnaire	Analysis of two multiple-choice questions answered by the students after participating in the ISCFC.

First, we collected data saved on the CFC:

1. The answers to the introductory questions: after selecting their location, users are presented with the average CF for both the region selected and the world. They are then asked to estimate whether their own CF will be lower, about the same or higher than these averages.
2. The average CF for the region selected.
3. The individual CF measured by the CFC after the user has answered the 50 questions composing this tool.

Of 5,970 students, we eventually used data from 1,722 students located in the USA and 248 students living in seven European countries (France, Germany, Greece, Italy, Sweden, Switzerland and the United Kingdom). With this corpus, we calculated two indexes measuring where the CF of the users fell in comparison to the national or worldwide CF average. First, we calculated the relative CF (RCF) compared to the average CF of the user's country, and then the relative CF (RCF) compared to the average CF of the world. If the RCF was higher than 10 per cent, the user footprint was considered above average; if the RCF was lower than -10 per cent, the user footprint was considered lower than the average; and if the RCF was between -10 per cent and 10 per cent, the CF was considered average.

Second, we analysed 28 posts written by students from six countries (USA, Croatia, Switzerland, Iceland, Bulgaria and Greece) on an online discussion forum where students were asked: “Did you use the calculator to identify areas in your life where you can make changes in order to reduce your footprint? Are you willing to make those changes?”. The contents of these posts were logged and anonymised while retaining the information concerning the country of origin. The analysis of the 28 posts was carried out by means of a thematic approach aimed at identifying and reporting salient patterns in the data corpus (cf. Attride-Stirling, 2011; Braun & Clarke, 2006).

Third, we analysed the answers to two questions from the post-activity questionnaire. The questions were: “How serious an environmental problem did you consider climate change to be before and after participating in the ISCFC?” and “After participating in the ISCFC, are you more likely to take steps to reduce your CF?”. We gathered these answers from 783 students.

The data from the CFC enlightened us concerning how students estimate their footprint and how they compare it to the national or world average (Table 6). These questions were addressed first for the European students and then for the students from the USA.

The result from the European students shows that while about 53.2 per cent of them have a calculated CF lower than their national average, most of them (90.8 per cent) estimated that their CF would be lower than the national average, and very few students (1.6 per cent) estimated that their CF would be above their national average. Concerning the worldwide average, almost all of the students have a calculated CF above the average, but about two thirds estimated that their CF would be either average or lower than the worldwide CF. The result from the students from the USA shows that 57.8 per cent of them have a calculated CF lower than the average for their state. About two thirds of them (65.6 per cent) estimated that their CF would be lower than the state average and more than ten per cent estimated that their CF would be higher than the state average. Concerning the worldwide average, all of them have a calculated CF above the average, and half of them were correct in predicting to be higher than the worldwide CF.

Table 6. Comparison between USA and European students in terms of their estimation of their own CF and the self-reported CF calculated by the CFC.

CF	USA students	European students	Findings
Comparison with national/state average CF			
Calculated	± 50% below	± 50% below	Similar reported values relative to the national average
Estimated	± 10% expected above average	± 0% expected above average	USA students more critical toward their CF
	± 65% expected to be below average	± 90% expected to be below average	
Comparison with global average CF			
Calculated	All above	All above	Similar reported values relative to the global average
Estimated	Less than half underestimated their CF	2/3 underestimated their CF	USA students more critical toward their CF

The analysis from the online discussion revealed a pattern of frequently discussed issues that can be categorised in five dimensions:

1. Students comment on and justify the estimation they made concerning their CF prior to using the CFC.
2. Students compare their reported CF with the national average and often express strong emotions such as "happy" or "shocked".
3. Students justify their CF with some specific behaviours (e.g. shopping habits and travel).
4. Students discuss how they could modify their everyday behaviour in order to decrease their CF.
5. Students discuss the concept of CF from a global perspective, rather than a local one as seen in the previous dimensions.

The data from the two multiple-choice questions in the questionnaire were analysed to gain a picture of how students perceive the impact of the ISCFC activity on their environmental behaviour and understanding. A majority of the students (86.46 per cent) considers that after participating in the ISCFC they were much more likely (30.01 per cent) or a bit more likely (56.45 per cent) to take steps to reduce their CF. Moreover, the percentage of students considering climate change as an extremely or somewhat serious issue increased from 64.23 per cent before, to 91.56 per cent after participating in the ISCFC. The percentage of students considering climate change as not at all serious or a little serious decreased from 35.75 per cent to 8.42 per cent after participating (Figure 9 in Study III).

This study shows how students report not only their CF calculated by the CFC, but also how they develop modes of reasoning and negotiate their own contributions in relation to both local and global consequences of their CF. The results of this study indicate that students seem to have difficulty in accurately estimating their CF. These findings call for reflection on what additional actions are needed to support the younger generation to become more aware of their own impact on the environment both locally and globally. According to the questionnaire, the students consider that the activity has changed their insight into climate change, declaring that they are more willing to take action, and that they view climate change as more serious a problem after participating. Consequently, the CFC may serve as a reasonably accurate and easy-to-use mediating tool, enabling students to understand and discuss their own local and global impact on the environment. Therefore, the results suggest that this kind of tool has the potential to support the turning of an invisible phenomenon that is difficult to manipulate into something that one can quantify and act upon, which may serve as a catalyst for triggering students' response toward mitigation.

Study IV: Questions as indicators of ocean literacy: Students' online asynchronous discussion with a marine scientist

Published as:
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Similar to Study III, this study investigates how an instructional activity from the I2I project supports communication and learning about marine environmental issues. In Study IV, the environmental issue in question is OA and its impact on marine communities and on our society.

In the instructional practice studied, 61 high school students from three different classes in California and Oregon, USA were introduced first to the issue of OA through a virtual laboratory (Table 7).

Table 7. Number of students participating in the study.

	Location	Subject	# of students	# of females	# of males	Age range
Class A	California	AP Environmental Science	24	9	15	16–18
Class B	Illinois	AP Environmental Science	25	14	11	16–18
Class C	Illinois	AP Biology	12	10	2	16–18
Total			61	33	28	

The teachers involved in this study implemented the I2I resources in their classrooms as part of their regular practices. This learning activity involved two main steps, described in detail below.

The students learn about the issue of OA by using a virtual laboratory, which is then followed by an online lecture, hosted on the VoiceThread platform.

The virtual laboratory on OA[22] is divided into three parts: First, the students navigate through an interactive slideshow presenting the OA background information. Second, the students run a virtual experiment aimed at finding out how OA affects sea urchin larvae development. Third, the students virtually measure the arm length of several sea urchin larvae they grew virtually and calculate the average length for each treatment.

1. *The interactive slideshow*. This first part includes an overview of rising CO_2 emission and its impact on seawater chemistry and living marine organisms. The slideshow starts by presenting the increase in CO_2 in the atmosphere through time in relation to human activity, and its environmental consequences: climate change and OA (Figure 12 A). Then, a drag-and-drop game introduces the concept of pH by comparing the level of acidity of different liquids (Figure 12 B).

[22] http://i2sea.stanford.edu/AcidOcean/AcidOcean.htm

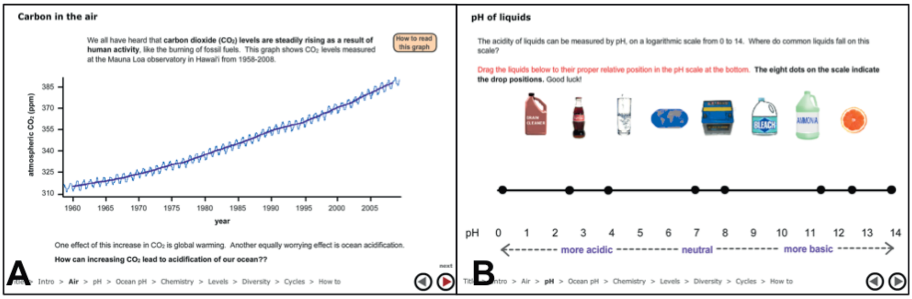

Figure 12. A. Increase in level of CO_2 at the Mauna Loa observatory (Hawaii, USA) from 1958–2008; B. Drag-and-drop game to place liquids in the right place on the pH scale.

The students are also introduced to the process of calcification (the building of calcium carbonate shells or skeletons) as one of the biological processes affected by OA. Carbonate chemistry and its link to calcification are described through step-by-step explanations of the chemical reaction (Figure 13 A) and how a drop in the pH level in the water can interfere with the calcification process. Finally, an interactive model demonstrates how future greenhouse gas emissions scenarios created by the Intergovernmental Panel on Climate Change (IPCC) would affect the different steps of the calcification. Students can travel in time between 1895 and 2090, shifting from one scenario to another to see how each chemical component will be affected, what the resulting pH would be and how that would impact on calcification in marine organisms (Figure 13 B).

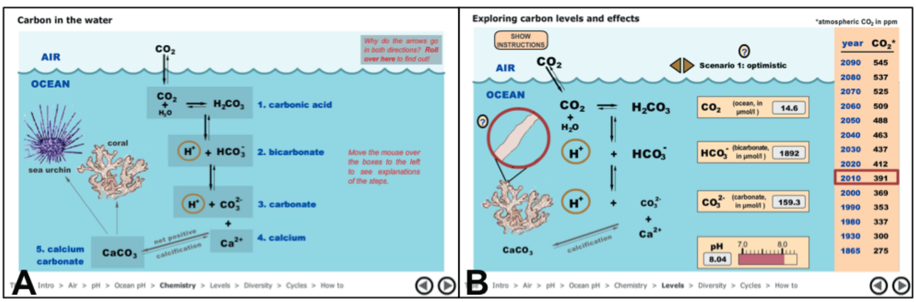

Figure 13. A. Explanation of the process of calcification; B. OA chemistry model based on three emission scenarios.

2. The virtual experiment. After completing the interactive slideshow, the students become virtual scientists, addressing the question: "How does OA affect marine life?". They run a virtual experiment by following a pre-designed experimental protocol testing the impact of OA on a specific calcifying organism: the larvae of the sea urchin *Paracentrotus lividus*. They culture sea urchin larvae in two different pH conditions (8.1 as control and 7.7 as the pH value expected for 2100). The students complete all the procedural steps of the experiment on their lab bench (Figure 14), such as setting up three replicate cultures for each pH condition, feeding the larvae, making water changes and observing larval development over time.

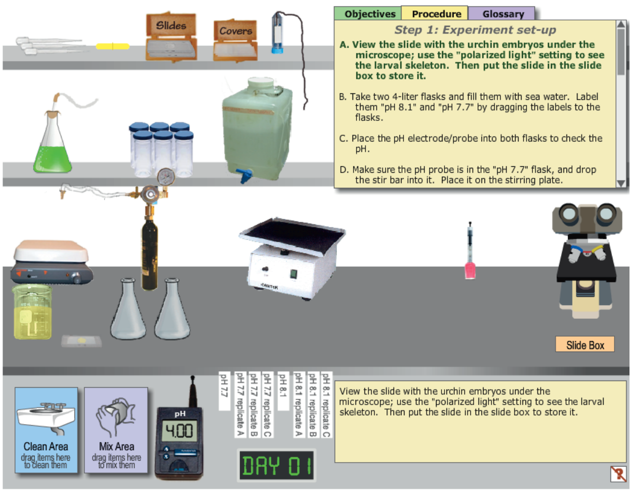

Figure 14. The virtual lab bench where students follow a protocol to culture sea urchin larvae at two different pH levels over a period of five days.

3. Measurement and analysis of the data. After five (virtual) days of culture, larvae from each replicate are mounted on microscope slides for measurement on a virtual microscope (Figure 15).

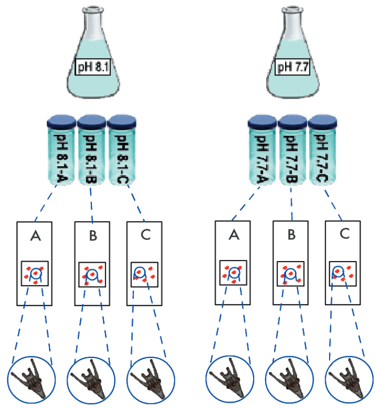

Figure 15. Illustration of the experimental design. The students grow larvae in two pH conditions. Larvae growing in each condition are cultured in three separate replicates. A sample from each of the six replicates is mounted on microscope slides. The students are to measure one larva from each of the six slides.

The virtual lab contains a database of 15 individual larvae at each pH (five larvae in each of the three replicates per treatment) and each student measures three randomly chosen larvae at each pH (one larva in each replicate; see Figure 16 A). In this respect, each student works on a unique data set. After completing the morphometric analysis, the students calculate the treatment means using their own unique measurements and then compare these subsample results with the entire statistical sample (Figure 16 B). The students discover that the effect of their subset can be very different from the complete data set. Aside from educational goals related specifically to OA, this virtual laboratory gives teachers the opportunity to address the scientific method and its limitations: an experiment is an abstraction from reality that scientists try to reach.

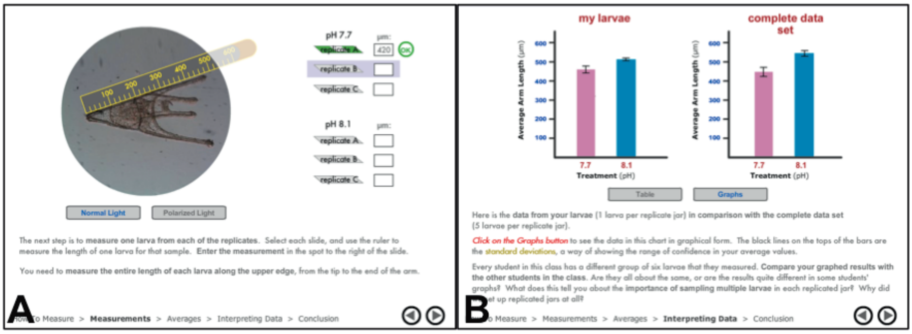

Figure 16. A. Measurement of the sampled larvae from each treatment; B. Comparison of the data from the student's sample (n=3) and the complete data set (n=15).

After engaging with the virtual laboratory on OA described above, the students watch an online interactive lecture hosted on the VoiceThread[23] platform (Figure 17).

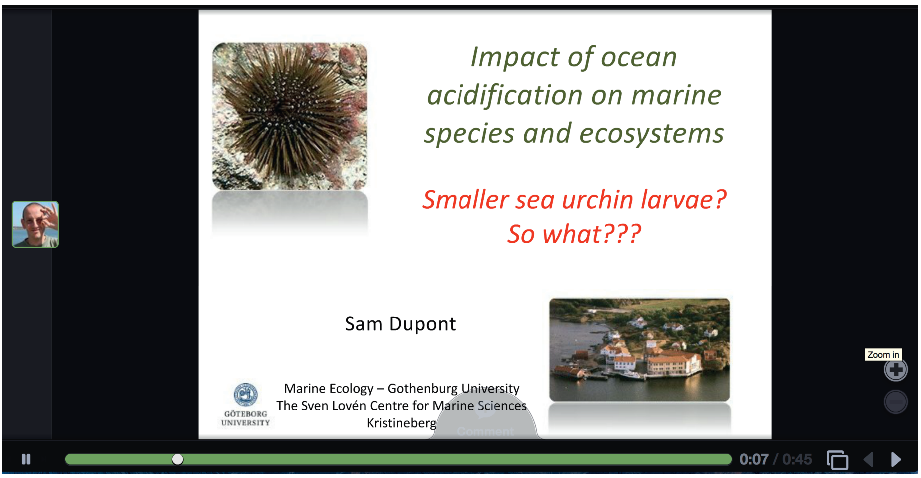

Figure 17. Screenshot of the first slide from the online lecture hosted on VoiceThread.

[23] https://voicethread.com/new/share/6521650/. This link contains a copy of the original interactive talk with the comments of the OA expert only. For ethical reasons, it does not include comments from students.

In order to create this online interactive lecture, the scientist uploaded a PowerPoint slideshow onto VoiceThread and added his audio comments on each slide. As many copies of the presentation were created as the number of participating classes so that each class could engage in a private discussion with the scientist. In the lecture, the scientist makes connections with the virtual experiment the students conducted in the previous step and the original experiment on which the virtual experiment is based. He also places the results of the experiment (sea urchin larvae growing slower in water with higher acidity) in a social and economic context. The presentation covers the following:

- The different steps of the scientific methods.
- A reminder of the experiments the students had just virtually run.
- Presentation of a similar scientific experiment conducted by the scientist's team.
- Explaining the direct and indirect economic impacts of OA.
- Explaining various impacts of OA on diverse marine species.
- Raising questions about what citizens can do to mitigate OA.
- Explaining the impact of carbon dioxide emissions caused by human activities.
- Opportunities to reflect on our own responsibility for this environmental issue.

The students were prompted by their teachers to watch the VoiceThread presentation and to record their questions to the scientist in the presentation. VoiceThread includes a function where users can embed their comments directly onto a chosen slide. The students can go to the slide, address the topic they have a question about, and add their question either by typing a comment or by recording their voice. The questions then become embedded chronologically in the slide and visible to all users (Figure 18). Later, the teacher informed the scientist that the students had posted their questions. The scientist then returned to the VoiceThread to see the slides on which the students had added their questions. After listening to or reading the students' questions, he recorded his replies. The teacher then let the students know that the answers to their questions were available on their copy of the VoiceThread. In this way, students and the scientist engaged in an asynchronous discussion through the VoiceThread platform.

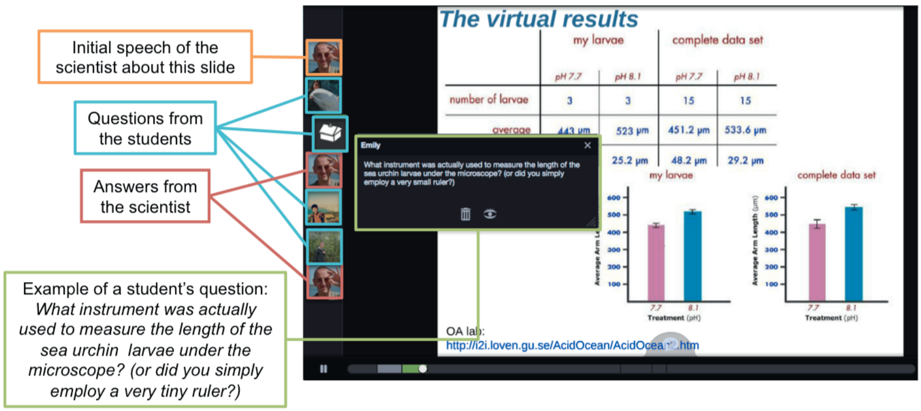

Figure 18. Screenshot presenting a slide from the interactive presentation with the corresponding icons of the users leaving a question or a comment.

The focus of this study is on the questions the students ask the scientist. It is guided by the following research questions:

• What kinds of reasoning can be discerned as premises in the students' question?

• What possibilities for enhancing students' ocean literacy are made possible by using these kind of tool-mediated activities in instruction?

The analysis of the students' questions was based on thematic analysis, a method identifying and reporting patterns or themes salient in a data corpus (Attride-Stirling, 2001; Braun & Clarke, 2006). For this study, the analysis focused on a data corpus consisting of 74 questions formulated by the students.

The thematic analysis revealed four categories of reasoning in the students' questions, illustrating the different kinds of premises on which the students based their questions (see Table 8).

Table 8. The four themes emerging from the thematic analysis of the students' questions.

Themes	Description
Comparison between everyday experiences & OA information	Making use of their everyday experience and comparing it to the information conveyed by the scientist in order to see how the two sources fit, or, alternatively, what kind of discrepancies have emerged.
Systems thinking	Displaying systems thinking about the information received where students include an understanding of the chain reaction association with OA.
Environmental concerns	Formulating questions that are concerned with the environmental aspect of OA and solutions that can be deployed.
Details concerning the experiment	Asking for further information about the experiment conducted by the scientist.

In the first category, the students make a connection between something they have previously seen, heard or experienced on the one hand and, on the other hand, the information they encountered in the presentation. The students make use of personal experiences and try to reconcile them with some of the new knowledge emerging from the online lecture. In this sense, the formulation of questions illustrates the ways in which the information in the interactive talk has mediated knowledge that becomes the premise for the students' further reasoning in their questions (cf., Wellington & Osborne, 2001).

The questions belonging to the second category show evidence of systems thinking. They suggest that students consider OA as an element of a complex system, where a modification of one component will trigger a chain reaction. The students engage in systems thinking through a degree of understanding that one modification in the marine environment would have repercussions throughout the ecosystem (Sterman, 1994). This kind of systems thinking and understanding of how factors interact is essential for developing ocean literacy (Cava, Schoedinger, Strang, & Tuddenham, 2005).

In the third category of reasoning, the students reflect on the way forward for our society in relation to OA, by discussing mitigation or adaptation to these new worrisome environmental conditions. This category includes questions that facilitate the opportunity to develop the third tenet of ocean literacy, the ability to make informed and responsible decisions concerning the ocean and its resources (Cava, Schoedinger, Strang, & Tuddenham, 2005). The questions in this category display an awareness of the importance of individual and societal responsibility towards this issue and of the need for change, which implies a developed understanding related to ocean literacy (cf., McKinley & Fletcher, 2010).

The questions in the fourth and last category ask for further details concerning the experiment described by the scientist. The questions probe the details of the experimentation in order for the students to evaluate the validity of the experiment and its results. These questions display what students already understand about the nature of science by asking questions around, for example, the importance of replicates, the need for funding and the potential problems researchers encounter while performing experiments.

The assumption behind this analysis is that formulating a question is a demanding task, where existing experiences and knowledge have to be transformed in the light of new ideas encountered. In other words, questions can be seen as indicators of the students' knowledge and reasoning about a certain topic (Wellington & Osborne, 2001).

To formulate their questions, students make use of scientific concepts (e.g. photosynthesis and the food chain) and display their mastery of these concepts in the way they build upon them to develop their understanding. These questions thus give clues to the students' premises for formulating their questions.

Several questions (see Q.72 above and Q.40 in Study IV) illustrate the unbalance between the science teaching of terrestrial and marine ecosystems. Students need the help of a more knowledgeable person to be able to make distinctions relevant to the marine environment. For example, the students display certain insights into photosynthesis taking place on land but do not make further distinctions with regard to photosynthesis in the ocean.

This activity offers an easy and affordable way to virtually bring valid, up-to-date and cutting-edge science to the classroom, which is often missing from both the school curriculum and the expertise of the teachers. Scientists are able to offer a broad range of knowledge and first-hand expertise in their fields. They have a deep understanding and experience of how their fields have developed to the current stage of knowledge. Scientists also have the ability to take a critical look at science itself, such as explaining weaknesses in the studies forming the body of knowledge and the areas where more knowledge is needed. In addition, these experts understand the implications of their field of research on a global scale and grasp its societal and political consequences. Scientists, therefore, offer a level of expertise in their area that many science teachers are unable to match.

In schools, natural sciences are often presented either as a series of facts or in an idealised form, with their complexities and uncertainties remaining hidden. Interaction with a scientist, though, gives students another entry point to the world of natural sciences with its complexity, uncertainty and choices.

In conclusion, this instructional activity exemplifies an affordable way of bringing marine science to the classroom by providing extensive expertise from a marine scientist. Students get a chance to contextualise and mobilise their pre-existing knowledge and apply it to the field of marine science. The holistic expertise of the marine scientist in his domain allows students to explore and reason around a wide range of ideas and aspects of natural sciences that go beyond the range offered by the school setting, especially in the field of marine science.

8. Discussion

Despite the importance of marine-related issues in contemporary society, very little research has been conducted in the field of marine education and even less on the potential of digital technologies for enhancing and promoting ocean literacy. Moreover, the existing studies are mainly impact studies aimed at measuring the knowledge gain after a given intervention, with little consideration of the communication dimension or the processes by which people come to know and understand the ocean. My thesis aims to contribute to addressing this research gap by investigating how online discussion platforms can support communication and learning about the marine environment.

The following questions have guided my research:

- How can the use of digital technologies support communication and learning of environmental skills associated with the ocean?
- What opportunities, challenges and limitations may be discerned in the use of such technologies when it comes to developing ocean literacy?
- What are the implications of ocean literacy for understanding the current environmental issues and for engaging in mitigation efforts?

Study I, a literature review, demonstrates that digital technologies in EE offer access to new experiences for students that would not otherwise be possible. However, this study also highlights the fact that the reviewed studies often show either an absence of significant effects on student learning or only slightly positive results in term of certain outcomes.

Study II, which investigates the use of a public Facebook page as a means to learn about and engage with marine science, shows that there is no guarantee that technological features aimed at promoting communication and collaboration will be taken up by the user. Rather, it is the context in which the communication takes place that is the most important factor.

Study III investigates what kinds of reasoning students engage in after using a carbon footprint calculator (CFC). The results from this study show how CFCs may serve as a mediating tool, transforming an invisible phenomenon into something that citizens can quantify, manipulate and ultimately act upon.

By scrutinising the questions posed by students to a scientist on an online platform that enables asynchronous discussions, Study IV exemplifies how to bring external expertise from marine scientists to the classroom, and how this give students a unique opportunity to mobilise their pre-existing knowledge and apply it to the field of marine science.

In this chapter, I will first address and answer my three research questions and then elaborate on some practical and theoretical implications before finishing with a brief conclusion.

Digital technologies as sources of support and as challenges to learning about the ocean: Answers to research questions 1 and 2

In this section, I will discuss how digital technologies support communication and learning about the marine environment by describing some of the opportunities, but also the limitations and challenges encountered, in my studies and how they relate to previous research.

Making the invisible visible

Making the invisible visible is a key opportunity offered by digital technologies in relation to environmental education. By enabling users to visualise something that would otherwise be invisible to them, digital technologies make it possible to engage with the environmental issues in more specific and relevant ways. As an illustration, I will draw a parallel with the use of digital technologies to improve a person's physical health. An increasingly sedentary lifestyle has been shown to contribute to health issues such as obesity (Kalman et al., 2015). Digital technologies such as pedometers, which count the number of steps being taken by the wearer, give users access to a measure of their physical activity, enabling them to relate to and consider the recommended number of daily steps. Recently, this tool has become accepted as providing a visualisation of physical movement that users can interact with. Analogously, the CFC aims at making visible another societal problem, namely the increase in greenhouse gases. CFCs turn our daily activities into a metric of our contributions to CO_2-related environmental issues. As with the pedometer showing its users their actual physical activity level, which they can compare with its recommended level, the CFC allows us to relate to the recommended CO_2 footprint. In other words, the CFC is a useful tool for supporting citizens in visualising, and consequently understanding, how their lifestyle compares with the environmental norms. But in order for this tool to become widely accepted and the carbon footprint metrics fully understood, this tool needs to be systematically implemented in education. This will enhance the naturalisation of how we measure our environmental impact at a personal level. This relates to Study III, where the findings show that the CFC gives students an opportunity to reflect on their daily behaviours and to obtain a value that helps them to visualise this concept. How the idea of the CF becomes visible for students can be seen from their responses to their individual results, for example: "`I was a bit shocked when I saw that my CF is a bit over the average for Croatia`". This illustrates how the students begin this activity with very limited insight into their CF and how they gradually appropriate it as a means to understand and communicate about their own impact on the environment.

Another way in which digital technologies make the invisible visible relates to the way scientists engage with the public at large. Scientific institutions have been criticised in the past for not engaging with the public and for being stuck in their ivory tower (Baron, 2010). Since scientists and citizens operate in different spheres, scientists have few opportunities to meet and interact with the public. Social media such as Facebook offer a unique opportunity for scientists and their research to become visible to the public on a daily basis and reach large numbers of citizens. As shown in Study II with the MBARI Facebook page, research results can now become accessible on platforms where users spend significant amounts of time. By making use of social media, marine research institutions can share their findings and offer the public an opportunity to interact with the scientists themselves. In this way, citizens can be in contact with science on a daily basis and have more opportunities to engage with scientific knowledge than ever before. Study IV presents another way for scientists to be in contact with the public, through virtually meeting with school students, which offers them opportunities to gain new insights into the culture of science that teachers might not be able to provide.

Digital technologies providing a new field of action

As demonstrated in my studies and as is evident from previous research in the multidisciplinary field of environmental science, digital technologies offer new means to make sense of and engage with global issues related to sustainable use of the Earth's resources. These technologies provide a field of action where users can experiment, make mistakes, get feedback and try again in ways that are different from paper-based learning activities. For example, taking decisions concerning a given piece of legislation (e.g. creating a marine protected area, or allowing fracking) can be informed by creating models based on current data that present environmental scenari indicating the consequences of any human input. Digital technologies also offer ways to develop systems thinking, which is vital for expanding ocean literacy, since these models can aggregate data from a wide range of parameters, large time and space scales, and forecast how each parameter will react to a change in another. Interactive environments also allow users to train in certain competencies that would be difficult to acquire otherwise, and in this sense, they help users become acquainted with the culture and practices of a given community. This is highlighted in Study IV, where students run a virtual laboratory in which they modify the level of acidity of seawater in order to culture sea urchin larvae and monitor their development through (virtual) time. This kind of experiment would not be possible to run physically within the time, safety and budget constraints of the school system. Virtually running this experiment gives students access to a "behind the science" tour of a scientific concept, in this case OA, which is intended to be appropriated. In this way, students are not only introduced to scientific facts but also presented with the scientific processes that lead to the establishing of such facts.

How digital technologies are used in context

Digital technologies do not only mediate the understanding of science through the interaction between the user and the scientist, they also provide opportunities to foster interaction between users who may be in the same room (the students in Study IV), or on the other side of the world (studies II and III). However, it is important to note that availability of resources for communication does not mean that in-depth discussion will automatically follow. Littleton and Howe (2009) offer an analogy of this by arguing that placing children around a table does not mean that they will start to collaborate and work together. This echoes the argument made by Kreijns, Kirschner and Jochems (2003, p. 341) concerning online tools, that "availability of communication media is necessary, but not sufficient". This argument is summarised by Jonsson (2004, no page number) as: "Meaningfulness is not intrinsic to technologies. Instead, meaning arises in a process of interpretation and interaction between participants and between participants and technologies."

An essential aspect of this challenge is related to the context perceived by the users. In Study II, the technology studied is a Facebook page that offers many features for fostering communication between users. The MBARI Facebook page is a public page shared by people who usually do not know one other. In such a public arena, the fans do not seem to invest time in interacting with each other or making their opinions public. This is illustrated by the interviewees' comments, such as "maybe because of shyness associated with kind of 'saying something wrong' and being corrected" and "I think people focus more on the content of the post than on the comments other people do." The context of a Facebook page, therefore, does not seem appropriate for creating an engaged community of users. Interestingly, though, these findings differ from those highlighted by Robelia, Greenhow and Burton (2011) while investigating the Hot Dish Facebook group. Robelia and her colleagues highlighted the users declaring that they valued the different opinions held by other Hot Dish users, even if they did not agree with them, as they helped them gain new perspectives on different aspects of climate change. The points of view of the users are particularly interesting here as they lie in the opposite direction to what was observed in Study II. The Facebook users in Study II described not daring to share their thoughts with strangers (although all shared an interest in MBARI and its goals) or not being very interested in other users' opinions, as illustrated by one of the interviewees when asked his thoughts on other fans' comments: "I'll give them a quick scan but I don't have the time, the energy, nor the inclination to respond/reply to each and every one of them".

In comparison with Study II, the engagement observed in studies III and IV is much more prominent. There are a number of reasons for this: First, the activities in Studies III and IV are part of formal education, where expectations and accountability for participation are required of the learners.

This is in contrast to the freedom associated with Facebook use during students' leisure time.

In Study III, students joined an online discussion forum that was shared with other students from around the world, in an environment supervised by teachers but maintained by the students. The interaction observed took the form of sharing feelings and interpretations about one's own emissions and providing guidance for other students concerning ways of decreasing their footprint, but also discussions concerning what students would be unwilling to change for the sake of the environment. The students' comments in this study displayed a wide range of opinions. This highlights the fact that environmental education does not come with a simple and universally correct answer that can be imposed on students, rather it is about the negotiation of different opinions and solutions that will have an impact on the planet and that must be understood by means of systems thinking.

In Study IV, students made use of another platform and connected with a scientist through an interactive slideshow. However, only the individual class and the scientist shared this platform. In this way, the platform mimics the dynamic that students encounter daily in their classroom. Therefore, one could argue that the culture that has been fostered among the students of this class transfers to the platform, allowing them to be comfortable in asking questions in this familiar community. These three studies illustrate that the technical features of a tool do not determine the kind of interaction that will evolve around its use. The contexts in which a tool is used, how it is used and what the features mean to its users, are key and demonstrate how important it is to study not only the outcome of a learning practice but also the interaction between the users and the tool in a specific context.

Appropriation

In order to engage in productive interaction with one another, learners also need to be able to appropriate the topic under discussion. In Study II, MBARI posts news on a daily basis ranging from marine engineering to marine biology and environmental science. In alignment with the features of the platform, the information provided is mainly visual, with short descriptions or explanations. This means that users are presented with a different topic every day, with very little information or context to help them appropriate the more profound aspects of the topic as an environmental issue. The pace of the platform also means that a posted story is likely to become obsolete within a couple of days. Therefore, users do not have time to get familiar with the topic in question, which, again, means that their opportunity to appropriate knowledge and become engaged is limited.

The situation is different in Study III, where, as discussed previously, students have opportunities to appropriate the notion of the carbon footprint on a very personal level through the use of the CFC, enabling rich and engaged discussions. While students begin the learning activity with little or no understanding of how large their calculated CF is in relation to the national average, they come to appropriate the concept and see which behaviours account for observed discrepancies between their carbon footprint and the national average. This appropriation is clear from the students' comments, for example: "`When I calculated my CF, I expected it to be average for where I live, which is Texas, but higher than the average for the world. I guess I expected this because I figured that the United States had one of the largest if not the largest CF`" but which, after they had made sense of the calculator's results, developed into a realisation of what the issue was really about: "[. . .] `probably because I took a trip to Spain by plane last year. Other than that I think it would be below average or at least equal.`" These appropriations may be seen as a step towards convincing the students to become involved actors in solving the problem at a local level: "`I am definitely going to get my family to try to carpool, that way I can reduce my CF and won't have it higher than the average Texan's`" and on a global level: "`Most people don't understand that we only have one Earth and we should try to do everything we can to keep it alive and healthy.`"

In Study IV, the students were given the opportunity to appropriate the concept of OA, and its impact on marine life, over time by running a virtual experiment. This appropriation was strengthened through the interaction with the scientist and his presentation. The features of VoiceThread allowed students to navigate back and forth through the slides of the presentation at their own pace. This enabled them to spend more time on some parts of the presentation, creating opportunities to familiarise themselves with, and eventually appropriate, important concepts related to OA. Kirby and Hulan (2012) indicated that an important component of the argumentative aspect of VoiceThread is linked to its waiting time. The asynchronous nature of this tool gives students time to respond, time that is not available in the flow of activities in the regular classroom. Echoing the aspect of time, Study IV demonstrates students' reflections about, and connection between, OA and their pre-existing experience. These connections between a wide range of ideas and experiences may have been facilitated by the delay between watching the presentation and recording their questions.

Nature and digital technologies

It is important to stress that the various opportunities to engage with environmental science described above do not imply that digital technologies should be seen as being in conflict with direct experiences of the ocean or the environment generally, but rather as a valuable complement for becoming an engaged citizen in relation to environmental issues. The recent explosion of the use of mobile technologies, untethered from a fixed location and providing Internet access at any moment from almost anywhere, challenges Pergam and Zaradic's (2006) claims that technology-based activities compete with outdoor activities. A vivid example of the intertwinement between technology and nature is the success story of Pokémon Go, an augmented-reality game for mobile devices. Providing game-based incentives, Pokémon Go requires users to walk about in order to catch virtual creatures called Pokémons ("Gotta catch 'em all"). Users are encouraged to go outside and explore new areas, and while Pokémon Go does not explicitly aim at connecting people with nature, it certainly provides a reason for doing so. For example, de Oliveira Roque (2016) tells how he went birding with his daughter, who made use of the outdoor experience to catch some Pokémons: "I was delighted when she asked me about a bird that appeared beside a Pidgey on her screen" (p. 34).

In addition, technologies have an impact on the safety aspect of the outdoor experience. For example, they can help ensure we are able to find our way, with tracking devices such as Google Maps. In extreme situations, the devices can be life saving. This was the case for the famous French sailor Florence Arthaud, who fell off her boat at night off the coast of Corsica. Fortunately, she had her phone on her and was able to call her family in Paris, who in turn contacted the local authorities. They were able to geo-localise her phone and rescue her (Le Monde, 2011). However, technology can also be the cause of accidents, which could have been avoided if people had been paying attention to their surroundings rather than their technology. Therefore, digital technology should not be seen as separate from or in conflict with our outdoor experiences but rather as an element of it, providing opportunities and challenges in its own right.

In our attempts to foster an ocean-literate society, digital technologies open up new ways of framing learning activities, inside and outside of school. These technologies offer ways of addressing environmental issues that did not exist before and that require the attention of researchers in order to be fully understood. As shown in Study I, digital technologies are as numerous as they are diverse. In order to determine the possibilities offered by a particular tool, one needs to conduct thorough investigations specific to the context in which the learning activity takes place. One of the challenges of this investigation resides in the time frames. New digital technologies appear on the Internet at a fast pace and with a variety of features. Simultaneously, research carried out to analyse the use of these tools is far slower, and there can often be a gap of a couple of years between the data collection and the publication of the results. This leads to a situation where research seems to always lag behind the development of the tools it studies. Nevertheless, these studies remain essential as they provide insights that enable some important conclusions to be drawn concerning the use of digital technologies in education.

Ocean literacy for engaging in mitigation efforts: Answer to research question 3

Below, I discuss the implications of the concept of ocean literacy for understanding the current environmental issues and for engaging in mitigation efforts.

The ocean's influence on us and our influence on the ocean

Until recently, it has not been possible to probe, measure or even properly observe the ocean; the technology just did not exist for something so big and so deep. Now, though, satellites, underwater vehicles and deep-sea sensors allow us to better document and understand the impact of our behaviours on the ocean. It is now more important than ever for the ocean to receive our full attention. The emergence of concern for the marine environment is reflected in the introduction of the concept of ocean literacy, a concept that represents a promising entry point to address the current environmental challenges.

Promoting ocean literacy among the public must be made a priority for a number of reasons: First, the ocean touches human beings in many ways, through the food we eat, the oxygen we breathe and the relaxation we get from swimming in it or gazing at the horizon beyond it. Since our behaviours are partially responsible for the environmental issues affecting the blood flow of the Earth (Pelegrí & Duró, 2013), it is vital to be aware of our accountability in order to make responsible changes. Our actions and behaviours are contingent on our understanding of and knowledge about the ocean (Kollmuss & Agyeman, 2002), making it essential to be ocean literate. Second, negative impacts on the environment in general, and on the ocean in particular, also harm already impoverished communities. We have a moral duty to future generations who will live on Earth to respect and preserve its ocean and its inhabitants. It is in this context that we should regard the concept of ocean literacy (Cerrone, 2013). This moral responsibility toward the environment in general, and the ocean in particular, aligns with Pope John Paul II's (1990) argument that:

> Certain elements of today's ecological crisis reveal its moral character […] The most profound and serious indication of the moral implications underlying the ecological problem is the lack of respect for life evident in many of the patterns of environmental pollution (no page number).

The ocean as entry point for global environmental awareness

Marine environmental issues offer an innovative entry point when it comes to addressing global environmental issues. For example, climate change and global warming have become very loaded and partisan-driven issues. As explained by the Pew Research Center (2016):

> Political fissures on climate issues extend far beyond beliefs about whether climate change is occurring and whether humans are playing a role [...] These divisions reach across every dimension of the climate debate, down to people's basic trust in the motivations that drive climate scientists to conduct their research (p. 4).

The science behind climate change is sufficiently complex that climate deniers use the public's lack of understanding of the scientific method to discredit the scientific community and minimise the human–driven carbon dioxide-related issues. Therefore, OA, also called "the other CO_2 problem" (Turley & Blackford, 2005), can serve as a less controversial and loaded point of entry to increase awareness of the human emission of greenhouse gases. Indeed, OA results in a straightforward chemical reaction that modifies the acidity of the seawater when CO_2 is added to it, an obvious scientific mechanism and, as such, less easy to contest or deny (Dupont, personal communication, 2017). Another example where a marine perspective on environmental issues can be valuable concerns agricultural practices. The fertilisers used on land run off to the ocean and are responsible for drastically decreasing the level of oxygen, creating marine dead zones. Becoming ocean literate has the potential to improve how we grasp our own impact and the impact of our society on the marine environment. It also allows us to understand all environmental issues on land and in the atmosphere that end up having an impact on the marine ecosystem for which we have a deep moral responsibility to care for and respect.

The necessity of developing systems thinking for becoming ocean literate

As discussed above, the tight interdependence between all aspects of the environment regardless of their location points to the centrality of the concept of systems thinking and its vital role when addressing environmental issues. Ben-Zvi-Assaraf and Orion (2005, p. 519) state that "this understanding is actually what science is all about". In line with this, I would argue that science needs to be framed as part of a social context rather than as a school topic isolated from the rest of the student's life. Dewey (1897, p. 6) clearly outlined the importance of considering science as a part of our social life: "I believe that the study of science is educational in so far as it brings out the materials and processes which make social life what it is." This also applies to marine science. It is important to understand that dealing with the challenges of marine environmental issues involves more than the application of one universal strategy. The marine issues are multifaceted and bring together all aspects of our society, being social, technological, ethical, cultural and economic in nature. The multidisciplinarity of these issues can be illustrated by students' questions from Study IV (that were not displayed in the article for reasons of space). "`How much do you think echinoderms would` `impact the medical economy through ocean acidification?`" exemplified the students' awareness of the connection between the health of the marine environment, the pharmaceutical industry and the economy in general. Another question suggested using bioengineering strategy to breed more resistant organisms: "`You mention that natural selection occurs for each level of pH and changes the urchin genotype. Does this mean that in the lab you could breed the survivors of the lowest pH trials and over time create an urchin that can survive extreme levels of acidity?`" This question touches upon how science and technology could help us adapt to the environmental issues triggered by modern lifestyles. Potential strategies to mitigate a marine environmental issue must be weighed one against the other and evaluated thoroughly in order to find the best solution in the context.

The ocean in formal education

In order to become ocean literate, the public needs to be provided with resources, such as the learning activities studied in this research. It also needs opportunities to be in contact with and engage with the marine issues in different ways, such as through interactions with scientists (as in studies II and IV) or through investigating its own influence on the environment (such as in Study III). The school system has served as a means for social change for a long time, for example in 1897 Dewey advocated for social progress in relation to schools: "I believe that education is the fundamental method of social progress and reform" (p.6). Therefore, as marine environmental issues become more and more pressing, and receive increasing attention, the development of ocean literacy needs to follow the same trend in formal education and become more prominent in science and environmental education. Despite their growing importance, marine topics are still handled very anecdotally in schools, for reasons such as the curriculum being already full, lack of appropriate content and resources, and insufficient pedagogical knowledge among the teachers (Gotensparre et al., 2017). While it has always been hard to add subjects in school, study of the ocean can permeate across the curricula. For example, as demonstrated in Study IV, photosynthesis is a topic that students seem to grasp relatively well ("`Like on ground, the plants can convert carbon dioxide to oxygen`"), but the same phenomenon in the ocean often leaves students puzzled. It would not take any time away from teaching about photosynthesis to use some marine examples instead of solely terrestrial ones. Therefore, it needs to be clear that marine environmental issues are relevant to all students, regardless of their location, as demonstrated by students living away from the coast who nevertheless will experience the impact of OA (“`How would OA affect our life in Woodstock Illinois?`”). Promoting ocean literacy in formal education and beyond would be an innovative and valuable point of entry for environmental issues. In addition, this novel approach to environmental and science education would require some innovative teaching resources and it is here that the use of digital technologies can provide new opportunities to implement learning activities, and in doing so further pursue the goal of making citizens ocean literate.

Practical and theoretical reflection

In this section, I will share some additional practical and theoretical thoughts as well as provide a brief discussion on the limitations of my studies and potential ways forward.

The framework used for this thesis allowed me to observe the learning and communication processes that occur when users interact with various online communication platforms in order to obtain insight into marine environmental topics. Practically, the use of digital technologies in formal education equips teachers with new and innovative ways to organise instruction, by providing the opportunity to run activities that were previously out of the reach of formal education (owing to, for example, limited budget, time, or safety measures). Moreover, digital technologies have the potential to bring different voices together in a way that would otherwise be difficult to actualise. For example, in studies II and IV, the Facebook and VoiceThread users received access to scientists’ expertise. This is an essential part of developing systems thinking as more knowledgeable persons become necessary in order to challenge preconceptions and to help less-knowledgeable users build their understanding of complex issues.

To continue this reflection, I will discuss briefly the importance of communication in our attempt to make citizens more ocean literate. In Vygotsky’s perspective on learning and development, language is the prime tool humans use to make sense of what happens in the world both as a way of reasoning/thinking and at a collective level for codifying human experiences.

The theoretical framework of this thesis has played a crucial role in my research through my focus on communication, which is central to human actions and scientific endeavours. This basis has allowed me to focus on the communicative activities of learning and thereby made it possible to analyse what the participants' reasoning means in the context of developing ocean literacy. As marine environmental issues are current and need to be acted upon now, engaging with them requires active participation and involvement that will have to be anchored in knowledge but also in the ability to engage in scientific discourse. This scientific discourse requires more than being able to recall definitions or facts; it also demands an understanding of, for instance, how claims are made and how models, with their degrees of uncertainty, are developed and communicated (Gyllenpalm, Wickman, & Holmgren, 2010). In other words, my theoretical framework has allowed me to investigate what Lemke (1990) refers to as "talking science", a cornerstone of any scientific participation, inside or outside of school.

Finally, I would like to refer to the limitations of my research. I have studied three online communication platforms out of the many that are currently in use. These platforms are constantly evolving, leading to a situation where it is difficult for research to present publications that reflect the current state of digital technologies. Moreover, one cannot easily predict what the future of digital technologies will involve in terms of applications for learning and communication. But despite these limitations, my research provides insights into how digital technologies can aid in increasing our knowledge about the ocean through the creation of new conditions for learning about this largely hidden environment. As much as the fast pace of the digital world presents challenges, it also allows us to imagine what the future holds. A fascinating future research direction would be to investigate the potential of more immersive digital technologies to transform the way in which we learn and communicate about marine issues. It would be beneficial to investigate what role technology can play when citizens are interacting directly with the ocean (e.g. tide pooling, diving and swimming). Marine encounters could also be created without getting wet by running an immersive virtual-reality experience (cf., Ahn et al., 2016) where the user virtually embodies a marine animal or a marine researcher underwater.

Conclusion

Half a millennium ago, Leonardo Da Vinci accurately illustrated the essential functions of the ocean by comparing it to the blood flow of a living organism (Pelegrí & Duró, 2013). This metaphor is now more relevant than ever as the health of the ocean, and subsequently the health of all inhabitants of the Earth, is at stake due to the alteration of the marine environment. Because of the vital functions of the ocean, citizens need to understand its importance and their role in protecting its environment. This thesis aims at contributing to the field of research in education by studying the role played by digital technologies in learning about marine environmental issues. By investigating different technologies, this thesis offers an overview of the range of impacts that technologies can have on the development of ocean literacy. The four studies illustrate how technologies open up new ways of learning about marine environmental issues, both inside and outside of school. Therefore, in essence, this thesis argues that online technologies constitute a cultural innovation that has the potential to improve the way we learn, communicate and experience the marine environment.

9. Swedish summary

Inledning

Föreliggande avhandling innehåller fyra delstudier som undersökt frågor som rör lärande om miljö där olika digitala teknologier använts. Mer specifikt har fokus varit på hur kunskaper om miljö kommuniceras och hur människor tillägnar sig dem. Två av studierna har ett särskilt fokus på den marina miljön och på vad som benämns som ocean literacy. I denna svenska sammanfattning kommer jag inledningsvis att rama in min studie genom att ge en övergripande bild av frågor som rör havet och dess tillstånd ur ett miljöperspektiv, därefter argumenteras för vikten av att medborgare utvecklar vad jag kommer att kalla ocean literacy.

Nittonhundratalets befolkningsexplosion har inneburit en ökande exploatering av jordens naturresurser. I dagsläget är det därför inte längre möjligt att bortse från den skadliga inverkan människors dagliga aktiviteter har på vår jord. Under senare år har havet kommit att uppmärksammas alltmer ur ett miljöperspektiv och det finns en rad olika anledningar till detta. Havet täcker mer än 70 procent av jordens yta och står för en betydande del av det syre vi andas. Det tillhandahåller nödvändigheter som mat och läkemedelssubstanser, och räknar man rent ekonomiskt står havet för tjänster som uppskattas till ett värde av mer än 1,5 miljarder dollar årligen (OECD, 2016), och det har också en väsentlig roll när det gäller hur vårt klimat regleras. Med andra ord, havet är avgörande för vår överlevnad och välfärd. Eftersom marina miljöproblem är direkt relaterade till våra dagliga aktiviteter, är det viktigt att allmänheten utvecklar förståelse för havet och dess betydelse för våra livsformer och vår framtid. Kunskaper om samspelet mellan havet och människan beskrivs i litteraturen i termer av *ocean literacy*, ett koncept som utvecklades i USA för mer än 10 år sedan (Cava, Schoedinger, Strang, & Tuddenham, 2005). Att vara ”ocean literate” innebär bland annat att ha grundläggande kunskaper om havet, att kunna föra ett samtal om havet och att kunna fatta välgrundade beslut i vardagen och inse vad dessa beslut får för konsekvenser för havet och dess resurser[24]. För att kunna delta i offentliga samtal om marina miljöfrågor är det således viktigt att ha en ändamålsenlig begreppsapparat, något som givetvis är centralt för alla vetenskaper och för all naturvetenskaplig utbildning (Lemke, 1990). Det teoretiska ramverk jag valt för min avhandling, det sociokulturella perspektivet på lärande och kommunikation, innebär dessutom att språket ses som avgörande för vårt meningsskapande och för vår förståelse av varandra och av världen (Vygotsky, 1978; Wertsch, 2007).

Avhandlingen innehåller fyra delstudier och en inledande kappa. Den första delstudien är en litteraturöversikt med fokus på forskning som undersökt användningen av digitala teknologier i miljöutbildning. Den andra delstudien fokuserar på ett stort marint forskningsinstituts kommunikation genom en Facebooksida, och de möjligheter detta sammanhang innebär för allmänheten att delta i diskussioner om havet. Kontexten i den tredje delstudien är interaktionen på ett diskussionsforum mellan gymnasieelever från olika länder där de diskuterar miljöbelastningen av deras livsstil och vardagsval. Diskussionen äger rum efter att eleverna använt ett instrument som är intressant i miljösammanhang, en så kallad koldioxidkalkylator (carbon footprint calculator). Denna studie fokuserar på vilken typ av resonemang som eleverna kan föra om koldioxidutsläpp när de använder en artefakt av detta slag som stöd. Den fjärde studien undersöker en undervisningsaktivitet som består av ett asynkront online-samtal mellan elever och en forskare, och som tar sin utgångspunkt i elevernas frågor. Aktiviteten innehåller olika delar där gymnasieelever först använt ett virtuellt labb för att lära om havsförsurning och därefter tittat på en virtuell presentation gjord av en marinbiologisk forskare som föreläser om ekonomiska och sociala konsekvenser av havsförsurning. Slutligen ställer eleverna frågor till forskaren online. Dessa frågor blir en del av presentationen och besvaras av forskaren, vilket genererar det asynkrona samtalet som fokuseras i studie fyra.

Syfte och frågeställningar

Avhandlingens övergripande syfte är att undersöka hur digitala teknologier bidrar till undervisning och kommunikativa aktiviteter som stöttar lärande och förståelse av miljökunskaper med anknytning till havet. Med utgångspunkt i

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[24] Det finns ingen vedertagen översättning av termen "ocean literacy" till svenska och som bevarar dess innebörd. Därför har jag valt att ha kvar den engelska termen i denna sammanfattning.

ett sociokulturellt perspektiv på lärande undersöks vad kommunikation via olika typer av online plattformar innebär för deltagarnas utveckling dels av generella miljökunskaper, dels av kunskaper som är mer specifikt kopplade till ocean literacy. De övergripande forskningsfrågor som ligger till grund för min avhandling är:

- Hur kan användningen av digitala teknologier stötta kommunikation och lärande av miljökunskaper förknippade med havet?
- Vilka möjligheter, utmaningar och begränsningar finns i användningen av sådana teknologier när det gäller att utveckla ocean literacy?
- På vilket sätt kan utvecklingen av ocean literacy stötta medborgare i att bli mer medvetna om och engagerade i att vidta åtgärder för att minska klimatförändringar och hantera miljöproblem?

Tidigare forskning

Den tidigare forskning min avhandling baseras på är förankrad i två forskningsområden. Det första området handlar om utbildning om miljöfrågor inom marina vetenskaper, och det andra är inriktat på vilken roll digitala teknologier har och skulle kunna ha i sådana utbildningssammanhang. Inom det första området diskuteras två frågor mer i detalj; dels den allmänna kunskapsnivån när det gäller den marina miljön i befolkningen och bland elever, dels hur lärare och forskare försökt bidra till att lösa några av de problem som är förknippade med utbildning inom marina vetenskaper.

Sedan början av 80-talet har ett tiotal studier publicerats om allmänhetens kunskaper om marina miljöfrågor. Dessa studier har genomförts med olika forskningsmetoder, bland annat enkäter och intervjuer, och de har fokuserat både barn och vuxna i en rad olika länder, främst i USA (Fortner & Mayer, 1983, 1991; The Ocean Project, 1999, 2009, 2011). Men även i länder som Storbritannien (Fletcher et al., 2009; Jefferson et al., 2014), Kanada (Guest et al., 2015) och Sydafrika (Ballantyne, 2004) har studier kring dessa marina teman genomförts. Trots skillnader i metoder, specifika frågor och kontexter visar de generella resultaten från alla studier att respondenterna har en begränsad förståelse av och kunskaper om marina miljöfrågor. Den samlade slutsatsen blir därför att det är angeläget att stötta medborgare i att utveckla kunskap om havet och dess betydelse för ett hållbart klimat. Det är viktigt att notera att dessa studier mestadels utgått ifrån en kvantitativ syn på kunskap och där produkten studerats, det vill säga vad människor kan om havet när de utsätts för frågor. I min forskning ligger intresset i första hand på att analysera lärandeaktiviteter, det vill säga på de lärprocesser som leder fram till kunskaper. Detta innebär inte att jag menar att produkten – kunskaperna – är mindre intressanta, men ur lärandesynpunkt ger kunskaper om processer mer ingående insikter i hur undervisning kan förändras, och i mitt fall, vilken roll digitala teknologier kan spela.

Den brist på kunskaper om marina miljöfrågor som påvisas i många studier kan delvis tillskrivas det faktum att havet inte ges något större utrymme i läroplanen eller i undervisningen i de flesta länder (Gotensparre et al., 2017). Det finns dessutom en uppenbar brist på forskning av ämnesdidaktisk karaktär som gäller marina teman. Utöver dessa institutionella problem som rör havets plats i utbildningssystemet, är det också ofta svårt att undervisa om havet av mer praktiska orsaker. För det första är havet svåråtkomligt för de flesta skolor av skäl som har med kostnad, scheman, säkerhet och annat att göra. Även för skolor i kustområden, som således har fysisk närhet till marina miljöer, får havet oftast ringa uppmärksamhet. Detta påpekas exempelvis av Long och Clark (2016) som menar att havet många gånger uppfattas som mindre centralt för samhället och våra livsformer, och därmed ser vi inte heller på havet med samma glasögon och vaksamhet som vi gör när det gäller andra delar av miljön. Dessutom, och detta är viktigt för mitt intresse, är havet en komplex företeelse som karaktäriseras av komplexa samband mellan ekologi, kemi, fysik, biologi och samhälleliga förhållanden som studeras inom human- och samhällsvetenskaper. Med andra ord är det svårt att förstå havet, som är ett system som täcker mer än 70 procent av vår planet och som består av komplexa samspel som sträcker sig från en mikroskopisk nivå till företeelser som är globala. Olika studier inom forskning om marina miljöfrågor och marin undervisning har försökt bearbeta dessa problem som gäller havets komplexa natur och tillgängligheten till naturupplevelser i havsmiljöer. Vissa forskare har fokuserat på betydelsen av en direktkontakt med den marina miljön (Greely, 2008), medan andra har utforskat möjligheter att lära om havet med hjälp av virtuella resurser. Ett exempel på forskare som utvecklat och studerat virtuella miljöer är Tarn och medarbetare (2008) som skapade ett virtuellt marinmuseum. Ett senare exempel är Ahn och kollegor (2016) som studerade användningen av augmented-reality-glasögon med syfte att öka medvetenheten om havsförsurning. Andra forskare har skapat virtuella applikationer som ger möjligheter att utföra experiment som annars skulle vara omöjliga att genomföra i ett klassrum (Fauville et al., 2011; Petersson, Lantz-Andersson, & Säljö, 2013a) och som belyser olika aspekter av havsmiljöer och marina miljöfrågor.

Teoretiskt perspektiv

Som tidigare nämnts utgår denna avhandling ifrån ett sociokulturellt perspektiv på lärande. I detta perspektiv ses lärande som något som sker i interaktion med andra och med de verktyg som finns tillgängliga i specifika aktiviteter. Med andra ord, kunskap och lärande uppstår och utvecklas i sociala praktiker (Lave & Wenger, 1991; Säljö, 2005). Således är fokus i min forskning inte individen och det individuella lärandet, utan snarare aktiviteten där lärande sker, och där deltagare, verktyg och det sociokulturella sammanhanget är viktiga komponenter.

Vårt beteende och lärande är nära kopplade till de kulturella redskap vi behärskar och använder. Till exempel ställs en person som skall multiplicera två tal med många decimaler inför helt olika aktiviteter beroende på om detta ska ske genom huvudräkning, med papper och penna eller med en miniräknare. I det första fallet kan problemet vara svårt att hantera, medan med en miniräknare så spelar det inte så stor roll om det finns många decimaler. Miniräknaren tar hand om centrala delar av det kognitiva arbetet. På detta sätt samspelar det kulturella redskap vi använder med hur vi lär och med vad som blir möjligt att lära. Inom det sociokulturella perspektivet används begreppet appropriering för att förstå hur vi gradvis lär oss något eller tillägnar oss exempelvis ett koncept eller ett redskap (Wertsch, 1998). Ett exempel på detta från studie III är när eleverna inledningsvis i aktiviteten, efter att ha använt koldioxidkalkylatorn, har liten eller ingen kunskap om begreppet koldioxidutsläpp. Under aktivitetens gång, och genom att först mata in data kring livsstilsvanor så att koldioxidkalkylatorn kan användas för att beräkna vars och ens individuella koldioxidutsläpp (det vill säga det som i litteraturen kallas carbon footprint eller på svenska koldioxidavtryck), blev de mer bekanta med begreppet och dess användning. Så småningom utvecklade de också en förståelse som gjorde att de använde begreppet när de jämförde och diskuterade olika aktiviteters miljökonsekvenser. Detta möjliggjorde att de kunde se sin egen miljöpåverkan och sätta den i relation till andra värden. Med andra ord, eleverna approprierade undan för undan detta begrepp, som ett kulturellt redskap som de kunde använda i sina analyser och diskussioner. I sociokulturell språkdräkt medierar koldioxidkalkylatorn ett begrepp som gör att vi kan utveckla vår förståelse av ett abstrakt fenomen (Wertsch, 2002).

Genom interaktion med andra skapar vi mening i de aktiviteter vi deltar i och därför utgör språket det viktigaste kulturella redskapet (Vygotsky, 1978). Språket, både muntligt och skriftligt, är också grundläggande för alla vetenskapliga sammanhang, då det är en förutsättning för att kunna formulera hypoteser, presentera resultat och argumentera (McGinn & Roth, 1999). Därför är det viktigt att lyfta fram vetenskaplig kommunikation i lärandeaktiviteter inom vetenskap (Lemke, 1990; Gyllenpalm, Wickman, & Holmgren, 2010). Det är också av denna anledning som min avhandling fokuserar på de kommunikativa aspekterna av ocean literacy.

Sammanfattning av studierna

Studie I

Fauville G., Lantz-Andersson, A., & Säljö, R. (2013). ICT tools in environmental education: reviewing two newcomers to schools. *Environmental Education Research, 20*(2): 248-283.

I studie I, som är en litteraturöversikt, granskas vad jag kallar två nykomlingar i skolan, nämligen miljöundervisning och användningen av digitala teknologier. Båda dessa inslag i skolan kan bidra till att stärka kritiskt tänkande om naturen och relationen mellan människa och natur. Kombinationen av dessa två områden är relativt ny och det finns inte särskilt mycket forskning om hur digitala teknologier kan stötta lärande i miljöundervisning.

Granskningen av fältet inleddes med en systematisk litteratursökning med utgångspunkt i nyckelorden ”miljöundervisning” och ”IKT”. Därefter gjordes ytterligare urval utifrån referenser i de artiklar jag fann i denna inledande genomgång. Urvalskriterierna för att inkluderas i denna litteraturstudie var att studierna skulle uppfylla en rad specificerade kriterier för att kunna betraktas som miljöutbildning (UNESCO, 1975, 1977). Totalt 16 studier inkluderades med utgångspunkt i dessa kriterier och dessa studier presenteras i artikeln med en sammanfattning av syfte, metod, sammanhang och forskningsresultat.

De sexton vetenskapligt granskade studierna visade sig vara genomförda med olika metoder (observationer, för- och eftertest, intervjuer, enkäter), kontexten skiljde sig åt (klassrum, muséer eller utomhusmiljöer) och olika digitala teknologier användes (mobiler, podcasts, augmented reality osv). Således visar granskningen av studierna att det finns en påtaglig mångfald både i fråga om metoder, kontexter och de teknologier som använts i forskningen, vilket gör det svårt att dra generella slutsatser. Ytterligare ett problem är att flertalet av studierna bygger på analys av pedagogiska verksamheter som designats och följts av forskare. Detta innebär i sin tur att dessa situationer mestadels bedrivits med stöd av forskare och andra som inte finns i skolan i den pedagogiska vardagen. Resultatet av litteraturöversikten visar dock att digitala teknologier ger möjligheter till lärandeaktiviteter som är intressanta för miljöundervisning och som dessutom skulle vara svåra eller till och med omöjliga att genomföra i skolan utan digitala teknologier.

Studie II

Fauville, G., Dupont, S., von Thun, S., & Lundin, S. (2015). Can Facebook be used to increase scientific literacy? A case study of the Monterey Bay Aquarium Research Institute Facebook page and ocean literacy. *Computers & Education, 82*, 60-73.

Studie II har bedrivits vid Monterey Bay Aquarium Research Institute (MBARI), ett världsberömt ideellt oceanografiskt forskningscenter beläget i Monterey Bay i Kalifornien. MBARI är ett marininstitut som specialiserat sig på innovation av teknik för att utforska havet. Genom min roll som utvecklare av MBARIs strategi för sociala medier fick jag möjlighet att studera hur MBARIs Facebooksida kunde utvecklas för att stötta lärande om marina frågor.

Studie II har två delar. Först genomförde jag en kvantitativ analys av effekterna av olika strategier för att öka besöken på MBARIs Facebooksida. Med utgångspunkt i min avhandlings fokus ses denna del mer som en bakgrund för mitt egentliga intresse. Den andra delen av studie II, som syftar till att utveckla förståelse av användningen av Facebook för att stötta interaktion om marina miljöfrågor, är helt i linje med min avhandling. Studien består av diskursanalytiska analyser (Starks & Trinidad, 2007) av interaktionen på MBARIs Facebooksida samt av intervjuer med åtta av sidans medlemmar. Resultatet visar att samspelet mellan medlemmarna och administratören på sidan begränsas till kommunikation som i de flesta fall har en fråga och svars-struktur med fokus på vetenskaplig fakta. Interaktionen mellan medlemmarna på Facebooksidan är också begränsad och det förekommer ytterst lite diskussion. Interaktionen förändras dock när innehållet i ett MBARI inlägg delas till en medlems egna Facebook-kontakter, vilket leder till att en diskussion uppstår bland dessa Facebook-vänner. Delade inlägg innebär att de som får möjlighet att ta del av inlägget ofta har en mer personlig relation till den som delar, och en slutsats är att detta medför ett större engagemang och vilja att diskutera marina miljöfrågor (Starks & Trinidad, 2007). Således kan man inte utgå ifrån att tillgången till digitala miljöer i sig är en tillräcklig förutsättning för att utveckla interaktion, utan det sociala sammanhanget och relationen mellan deltagarna är viktiga aspekter för att skapa engagerade diskussioner.

Studie III

Fauville, G., Lantz-Andersson, A., Mäkitalo, Å., Dupont S. & Säljö, R. (2016). The carbon footprint as a mediating tool in students' online reasoning about climate change. In O. Erstad, K. Kumpulainen, Å. Mäkitalo, K. C. Schröder, P. Pruulmann-Vengerfeldt, & T. Jóhannsdóttir (Eds.), *Learning across contexts in the knowledge society*. Rotterdam, the Netherlands: Sense Publishers.

Studie III bygger på idén att ungdomar bör känna till hur deras egna aktiviteter påverkar miljön för att de ska kunna utveckla både förståelse för hållbarhet och en insikt i vilken påverkan egna aktiviteter har på deras koldioxidavtryck. Sådana insikter är viktiga för att man ska kunna göra informerade val i vardagen. Denna typ av insikter bygger dock på komplexa samspel och dessutom är begreppet koldioxidavtryck abstrakt och miljökonsekvenserna osynliga. Koldioxidräknaren som mäter avtryck erbjuder ett sätt att synliggöra och kvantifiera dessa genom att låta användaren mata in information om sin livsstil i olika avseenden och räknaren ger därefter användaren ett värde som uttrycks i kilo koldioxid per år. Studie III syftar till att förstå hur studenters resonemang stöds av en sådan artefakt som ger dem tillgång till kvantifieringar av den egna klimatpåverkan. Genom analyser av elevers textinlägg på en lärplattform undersöks hur de engagerar sig i diskussion om koldioxidutsläpp, dess uppkomst och konsekvenser.

Kontexten för Studie III är en lärandeaktivitet på en lärplattform där 1970 gymnasieelever från olika länder deltog inom ramen för denna studie. Konceptet för aktiviteten är att eleverna, som en inledning, skriver in uppgifter om sin livsstil. Därefter får de försöka förutsäga huruvida deras klimatpåverkan kommer att visa sig vara över, under eller ungefär samma som genomsnittet i deras eget land (eller stat i USA). Efter det använder de en koldioxidkalkylator där de får besvara femtio livsstilsfrågor som ger uppskattade svar med ett personligt mått på deras koldioxidavtryck. Därefter interagerar eleverna på ett diskussionsforum där de reflekterar kring sina resultat, jämför dem och diskuterar hur man kan minska sin klimatpåverkan. Slutligen svarar eleverna på en enkät. I denna studie analyseras hur användningen av en koldioxidkalkylator och efterföljande diskussioner stöttar eleverna i deras reflektioner kring klimatfrågor och koldioxidutsläpp. Studien bygger på tre typer av data:

- De förutsägelser som 1722 studenter från USA och 248 studenter från Europa gjorde innan de svarade på livsstilsfrågorna och beräknade sitt koldioxidavtryck.
- Innehållet i 28 inlägg som publicerades på lärplattformen där de diskuterade sina respektive koldioxidavtryck och hur de skulle kunna minska sin miljöpåverkan.
- Svaren på två frågor från enkäten om denna lärandeaktivitet och deras syn på klimatförändringar.

Resultatet visar att eleverna tenderar att underskatta sitt koldioxidavtryck både i en nationell jämförelse och med ett världsgenomsnitt. Denna trend var tydligare hos europeiska studenter än hos amerikanska studenter. Analysen av inläggen från eleverna visar en struktur som kan delas in i fem dimensioner, där eleverna:

- berättar om sin förutsägelse av sitt koldioxidavtryck jämfört med regionens genomsnitt.
- jämför koldioxidavtryck som erhållits via koldioxidräknaren med den egna regionens genomsnitt. I denna dimension finns återkommande uttryck för känslor av förvåning när de antingen trodde sig ha ett lägre eller högre avtryck. Dessa resultat inkluderar även uttryck för glädje när deras avtryck var lägre än genomsnittet i regionen och skuld när det var högre.
- motiverar skillnaden mellan egna koldioxidutsläpp och det nationella genomsnittet genom att beskriva vissa aktiviteter som påverkar resultaten, till exempel hur en resa kan leda till högre koldioxidavtryck än genomsnittet.
- diskuterar strategier för att minska sitt avtryck.

- diskuterar koldioxidavtryckbegreppet som ett globalt problem snarare än utifrån ett lokalt perspektiv.

Data från enkäten visar att majoriteten av eleverna (86,46 procent) svarar att de är mer benägna att vidta åtgärder för att minska sina koldioxidutsläpp efter att de deltagit i aktiviteten.

Studiens slutsatser är att studenterna närmar sig aktiviteten med mycket begränsad kunskap och ofta har missuppfattningar när det gäller deras egna bidrag till klimatproblemen. Denna läraktivitet möjliggjorde för eleverna att reflektera över sitt ansvar och vilka åtgärder de kunde vidta för att minska den egna klimatpåverkan. Sammanfattningsvis visas att detta verktyg ger goda möjligheter att omvandla ett abstrakt begrepp till ett konkret redskap för att mäta och förstå egna aktiviteters konsekvenser för miljön.

Studie IV

Fauville, G. (in press). Questions as indicators of ocean literacy: Students online asynchronous discussion with a marine scientist. *International journal of Science Education.*

Studie IV syftar till att bättre förstå de möjligheter som en plattform av typen VoiceThread kan innebära för lärande om marina miljöfrågor. VoiceThread är en slideshow som låter användaren titta på presentationer i sin egen takt och navigera fram och tillbaka genom presentationen och ställa frågor som bäddas in i själva presentationen.

I Studie IV ingår flera olika moment: först ingår en läraktivitet där eleverna arbetar med ett virtuellt laboratorium som fokuserar på orsaker och konsekvenser av havsförsurning. Efter det tittar eleverna på en presentation som förklarar de sociala och ekonomiska konsekvenserna av havsförsurning gjord av en forskare på VoiceThread. Eleverna uppmanas därefter att ställa frågor till forskaren genom att spela in sin röst eller skriva kommentarer som sedan integreras i presentationen. Forskaren kan då besvara frågorna, och därigenom skapas en asynkron diskussion mellan eleverna och forskaren.

I studien fokuseras på elevernas frågor till forskaren, som analyserats med hjälp av tematisk analys (Attride-Stirling, 2001). Analysen är gjord utifrån ett empiriskt underlag bestående av 74 frågor från ett sextiotal elever med fokus på hur eleverna resonerar om havsförsurning och vad de tar upp av innehållet som tidigare presenterats både i arbetet med det virtuella labbet och i föreläsningen på VoiceThread. Efter att ha transkriberats, kodades frågorna utifrån de resonemang eller den tematik som de uppvisar. Analysen av frågorna som eleverna ställde visar på fyra teman eller premisser:

- Frågorna illustrerar att eleverna jämför sina egna erfarenheter med informationen från forskaren: Studenterna försöker med andra ord jämföra sina egna tidigare erfarenheter med den information de fått del av. När dessa idéer inte överensstämmer, ställer de frågor där de kopplar till sina tidigare kunskaper.
- Frågorna illustrerar ett systemtänkande: studenter ser havsförsurning som en del av det komplexa system som havet utgör. Dessa frågor visar att eleverna börjar förstå att en förändring i ett led kommer att få återverkningar i ett annat led.
- Frågorna illustrerar miljöhänsyn: eleverna reflekterar över konsekvenserna av beskrivna miljöförändringar för samhället.
- Frågorna illustrerar detaljer om vetenskapliga experiment: närvaron av forskaren ger eleverna möjlighet att komma i kontakt med den vetenskapliga kulturen. Frågorna visar elevernas förståelse av den typ av vetenskap och det sammanhang i vilket forskningen genomförs.

Ett generellt resultat är att elevernas visar bristande kunskap och insikter när det gäller marina miljöfrågor, även om de uppvisar viss kunskap om generella landbaserade miljöfrågor. Exempelvis visar några elever en god förståelse av fotosyntesen som sker på jorden, men har inte alls samma kunskap när det gäller den marina miljön.

Slutsatsen som dras är att denna läraktivitet erbjuder möjlighet att ställa frågor till en forskare som kan föra in sin kunskap inom området som skiljer sig från lärarnas och därmed ger ytterligare perspektiv på innehållet. Genom denna typ av läraktivitet ges eleverna således med teknologins hjälp möjlighet att på ett enkelt sätt få möta en forskare och därmed komma närmre en vetenskaplig kultur som går utöver vanlig klassrumsundervisning.

Diskussion

Inledningsvis i diskussionen behandlas de två första forskningsfrågorna: Hur kan användningen av digitala teknologier stötta kommunikation och lärande av miljökunskaper förknippade med havet och vilka är möjligheterna, utmaningarna och begränsningarna i detta sammanhang?

Som svar på dessa frågor visas hur tekniken bidrar till att synliggöra det osynliga (som koldioxidavtryck i Studie III) dvs. den digitala teknologin möjliggör en omvandling av ett abstrakt begrepp till en konkret enhet som eleverna kan använda som ett redskap i sina diskussioner och för sin förståelse.

Digitala teknologier har också de fördelarna att användarna kan experimentera, göra misstag och se vilka konsekvenserna blir på ett helt system då någon parameter ändras. Exempelvis kan eleverna observera konsekvenser av havsförsurning i ett virtuellt laboratorium genom små experiment som sedan kopplas till autentiska data från aktuellt forskning. Detta illustreras i Studie IV där eleverna utför ett komplext experiment i den digitala miljön som annars inte hade varit möjligt att genomföra. Dessutom gör teknologin det möjligt för forskare att på ett enkelt sätt diskutera med elever och medborgare online, vilket illustreras i Studie II och Studie IV.

Studie II visar både hur digitala teknologier erbjuder nya sätt att kommunicera men också att denna kommunikation inte kan tas för given. På MBARIs Facebooksida erbjöds olika möjligheter att interagera, men resultatet visade att gedigna diskussioner var sällsynta. Således räcker det inte att teknologin erbjuder många olika sätt att interagera, det måste också skapas en plats där diskussioner känns meningsfulla för deltagarna. I studie II blir det tydligt, att eftersom kontexten är en offentlig Facebooksida där deltagarna inte känner varandra, är det svårt att skapa diskussioner. I Studie IV däremot är kontexten en klass där eleverna känner varandra väl, vilket gör att eleverna känner sig trygga vilket leder till att det uppstår ett gott diskussionsklimat.

Därefter diskuteras den tredje forskningsfrågan som handlar om den roll som utvecklingen av ”ocean literacy” kan spela när det gäller medborgares medvetenhet om och vilja att vidta åtgärder för att minska klimatförändringar och hantera miljöproblem. Trots vikten av att ha kunskap om havet är marinvetenskap något som sällan fokuseras i undervisningen i skolan. Elever har oftast mycket större kunskap om miljöproblem på land än miljöproblem relaterade till havet. Detta innebär en betoning av landbaserade miljöfrågor som i litteraturen kallas the ’terrestrial bias’, och som är vanligt förekommande inom undervisning om miljö. Denna bias är något som utrycks som viktigt att uppmärksamma för att stötta en utveckling mot att utbilda elever inom marina miljöfrågor (e.g., Gotensparre et al., 2017; NGSS Lead States, 2013). I Studie IV blir detta tydligt när elever visar att de har god kunskap om fotosyntes som förekommer på land men är mycket mindre säkra på vad detta betyder när den uppträder i havsmiljön.

Diskussionen avslutas med en reflektion om mina studiers begränsningar relativt att det är svårt att dra slutsatser som är generellt giltiga för alla digitala teknologier då jag främst studerat tre virtuella plattformar. Dessutom är det svårt att förutse vad framtida teknologier inom utbildningsområdet betyder för möjligheter till lärande. Trots dessa begränsningar argumenterar jag för att min avhandling är ett viktigt bidrag inom detta forskningsområde eftersom mina resultat illustrerar hur digital teknik erbjuder nya förutsättningar för studier av den marina miljön som ofta är svåråtkomlig och abstrakt för de flesta människor.

Slutligen lyfter jag flera anledningar till att det är viktigt att bidra till att utveckla människors kunskaper om havet. Först och främst påverkar havet oss alla, oavsett var vi är på jorden, och våra aktiviteter påverkar i sin tur havet. Därför är det viktigt att medborgare förstår hur deras livsstil kan ha en negativ inverkan på havet på genom de dagliga val vi gör när vi nyttjar tjänster och produkter. Att utveckla ”ocean literacy” bidrar dessutom till ökad kunskap och förståelse om alla andra miljöproblem på land och i atmosfären.

Leonardo Da Vinci illustrerade för över 500 år sedan betydelsen av havet genom att jämföra det med levande organismers blodcirkulationssystem. Idag, mer än någonsin tidigare, är denna metafor relevant och pekar på den primära betydelse som den marina miljön har för våra liv och hur viktigt det är att vi alla skaffar oss kunskaper som kan hjälpa oss att anpassa våra dagliga aktiviteter. Digitala teknologier har en viktig roll i att hjälpa oss att bli mer bekanta med den marina miljön och min avhandling visar att digitala teknologier är en kulturell innovation som kan stötta utvecklandet av ”ocean literacy”

10. French Summary

Introduction

Il y a plus de 500 ans, Leonardo Da Vinci illustrait l'importance de l'océan en le comparant au système circulatoire d'un organisme vivant. Plus que jamais, cette métaphore nous rappelle le rôle primordial joué par le milieu marin sur nos vies et l'importance pour chacun d'entre nous de posséder des connaissances marines pouvant nous aider à adapter notre comportement quotidien. Cette thèse comporte quatre études se penchant sur les opportunités, les limitations et les défis posés par l'utilisation de différentes technologies digitales dans le cadre de l'apprentissage des problèmes environnementaux marins.

Vu le rôle essentiel de l'océan pour la survie de notre espèce, celui-ci est au cœur de ma thèse. L'océan couvre plus de 70 pourcents de la Terre, nous procure entre autres nourriture, substances médicinales, une importante partie de l'oxygène que nous respirons, des emplois et une source de relaxation. Il régule aussi notre climat. En d'autres mots, l'océan est essentiel pour la survie et pour le bien-être de chacun d'entre nous. Pourtant, les pressions humaines ne cessent de détruire les populations et les habitats marins, de changer la température et la chimie de l'eau de mer, mettant notre propre survie en danger. Etant donné ces problèmes environnementaux marins liés au comportement de chaque citoyen, il est important que le public comprenne l'influence que l'océan a sur lui ainsi que sa propre influence sur l'océan. Le discernement de cette interaction entre l'océan et l'homme est ce que l'on appelle l'« ocean literacy », un concept développé aux Etats-Unis il y a plus de 10 ans (Cava, Schoedinger, Strang, & Tuddenham, 2005). Être « ocean literate » signifie avoir une certaine connaissance de l'océan, être capable d'avoir une conversation à son sujet et de prendre des décisions avisées concernant l'océan et ses ressources[25]. L'éducation aux sciences marines

[25] Il est difficile de traduire le terme « ocean literacy » en français tout en respectant l'entièreté de sa signification. Certains parlent de connaissances marines mais dans ce cas, on perd la notion de communication et de prise de décision que le concept d'« ocean literacy » inclut. J'ai donc décidé de conserver le terme anglais dans ce résumé.

constitue l'un des principaux instruments pour développer l'« ocean literacy » du public et se base sur des compétences liées aux sciences naturelles et environnementales.

Afin de prendre part à ces débats de société concernant les problèmes environnementaux marins, il est crucial d'être capable d'adopter un discours adéquat. L'importance de la communication se retrouve dans la définition même de l'« ocean literacy », qui stipule qu'une personne « ocean literate » est capable de discuter de l'océan de façon cohérente. L'importance de la communication est aussi centrale à toute entreprise scientifique et doit donc rester au cœur de l'éducation des sciences en général (Lemke, 1990). De plus, dans la perspective socioculturelle de l'apprentissage utilisée dans cette thèse, le langage joue un rôle primordial pour donner sens au monde qui nous entoure et pour interagir les uns avec les autres (Vygotsky, 1978; Wertsch, 2007).

Cette thèse contient quatre études. La première est une revue de la littérature concernant l'utilisation des technologies digitales pour l'éducation à l'environnement de façon générale. La seconde se penche sur l'utilisation d'une page Facebook par un important institut de recherche marine et sur les opportunités pour les fans de cette page de s'engager dans des discussions fructueuses concernant l'océan. La troisième étude porte sur l'utilisation d'un calculateur d'empreinte carbone ainsi qu'un forum de discussion utilisé par des jeunes du secondaire dans différents pays. Cette étude s'intéresse au type de discussion et raisonnement auquel les jeunes prennent part en relation avec leur empreinte carbone. La quatrième étude se concentre sur une activité scolaire où des élèves du secondaire utilisent tout d'abord un laboratoire virtuel pour se familiariser avec le problème d'acidification de l'océan avant de suivre la présentation virtuelle d'un scientifique concernant les impacts économiques et sociaux de l'acidification de l'océan. Cette étude analyse les questions posées par des élèves au scientifique durant la présentation virtuelle.

Objectif

Ma thèse vise à mieux comprendre comment les technologies digitales peuvent favoriser la compréhension des problèmes environnementaux liés à l'océan. Fondée sur une perspective socioculturelle de l'apprentissage, ma recherche vise à explorer la contribution de ces technologies à la communication comme moyen de développer l'« ocean literacy ». Les questions de recherche sont les suivantes :

1. Comment les technologies digitales soutiennent-elles la communication et l'apprentissage liés aux problèmes environnementaux marins ?
2. Quelles sont les opportunités, les limitations et les défis de l'utilisation des technologies digitales afin d'améliorer l'« ocean literacy » ?
3. Quelles sont les implications de l'« ocean literacy » en ce qui concerne les problèmes environnementaux marins et leur atténuation ?

Cette thèse comporte deux parties. La première partie décrit la recherche liée à l'apprentissage des sciences marines et l'utilisation des technologies digitales en éducation. Elle décrit aussi le contexte théorique sur lequel cette thèse est fondée, décrit les méthodologies et résume les quatre études[26] qui constituent la seconde partie de cette thèse.

Contexte

Cette thèse est ancrée dans deux domaines de recherche ; l'éducation des sciences marines et l'utilisation des technologies digitales en éducation.

Ma thèse se penche tout d'abord sur l'éducation des sciences marines et traite deux thèmes ; la recherche sur le niveau de connaissance du public concernant le milieu marin, et la manière dont les chercheurs tentent de surmonter certains problèmes inhérents à l'éducation aux sciences marines.

Depuis le début des années 80, une quinzaine d'études ont été publiées concernant la connaissance du public du milieu marin. Ces études ont fait utilisation de différentes méthodes de recherche tels que questionnaires, interviews, et enquêtes téléphoniques. Ces études ont été menées auprès de différentes catégories de population (allant des enfants aux adultes), dans

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Étude I: Fauville G., Lantz-Andersson, A., & Säljö, R. (2013). ICT tools in environmental education: reviewing two newcomers to schools. *Environmental Education Research, 20*(2): 248-283.
Étude II: Fauville, G., Dupont, S., von Thun, S., & Lundin, S. (2015). Can Facebook be used to increase scientific literacy? A case study of the Monterey Bay Aquarium Research Institute Facebook page and ocean literacy. *Computers & Education, 82*, 60-73.
Étude III: Fauville, G., Lantz-Andersson, A., Mäkitalo, Å., Dupont S. and Säljö, R. (2016). Digital media as cultural tools: Understanding of and responding to climate change. In O. Erstad, K. Kumpulainen, Å. Mäkitalo, K. C. Schröder, P. Pruulmann-Vengerfeldt, & T. Jóhannsdóttir (Eds.), *Learning across contexts in the knowledge society* (pp. 39–60). Rotterdam, the Netherlands: Sense Publishers.
Étude IV: Fauville, G. (accepté). Questions as indicators of ocean literacy: Students online asynchronous discussion with a marine scientist. *International Journal of Science Education*.

différents pays (par exemple Ballantyne, 2004 ; Fletcher et al., 2009; Guest et al., 2015 ; Fortner & Mayer, 1983). Ces études mettent en évidence une compréhension limitée du milieu marin par les citoyens en général et défendent l'idée qu'il est primordial d'aider ceux-ci à acquérir une connaissance de l'océan plus développée. Il est important de noter que ces études sont principalement normatives et s'intéressent à la connaissance comme une fin en soi tandis que ma recherche est dédiée au processus d'apprentissage.

Ce manque de connaissance du milieu marin peut partiellement être attribué au fait que l'océan est en grande partie absent des programmes scolaires (Gotensparre et al., 2017) et au manque de recherches concernant l'éducation aux sciences marines. Au-delà de ces problèmes institutionnels, la nature même de l'océan contribue à la difficulté d'intégrer son étude à l'école. Tout d'abord l'océan est difficile d'accès étant donné que la majorité de l'océan reste cachée sous la surface et dans les profondeurs marines. C'est pour cette raison que Long et Clark (2016) considère que l'océan est souvent perçu comme éloigné de la société humaine et de nos préoccupations. Ensuite, le fonctionnement de l'océan résulte d'une série de connections étroites entre l'écologie, la chimie, la physique, la biologie et l'aspect sociétal de ce système. En d'autres termes, il est compliqué de comprendre ce système qui couvre plus de 70 pourcents de notre planète et qui est constitué d'interactions complexes allant de l'échelle microscopique à l'échelle mondiale. Différentes études ont tenté d'aborder ces problèmes d'accessibilité et de complexité. Certains chercheurs se sont penchés sur l'importance du contact direct avec le milieu marin (Greely, 2008), ainsi que la participation à des expériences scientifiques (Cummins & Snively, 2000) tandis que d'autres ont exploré les possibilités virtuelles. D'autres chercheurs ont développé des activités où les élèves peuvent manipuler des données scientifiques réelles en conduisant des expériences en classe afin de comprendre comment la modification d'un paramètre peut créer une réaction en chaine (Foley et al., 2013). D'autres chercheurs se sont intéressés à la création d'expériences virtuelles qu'il serait impossible de conduire en classe (Fauville et al., 2011; Petersson, Lantz-Andersson, & Säljö, 2013a).

Ma thèse contribue à améliorer l'éducation aux sciences marines à travers l'utilisation de technologies digitales. Les technologies se sont introduites dans un grand nombre de nos activités quotidiennes, tiennent dans la paume de notre main et nous maintiennent connectés à tout moment. Ces technologies sont aussi multimodales, alliant images, sons, vidéos, textes ou encore animations. Elles créent une expérience riche et engageante, qui peuvent nous faire visiter les endroits les plus reculés (Jacobson, Militello, & Baveye, 2009), mener des expériences complexes (Petersson, Lantz-Andersson, & Säljö, 2013a) et même rendre visibles des phénomènes invisibles à l'œil nu (Ryoo & Linn, 2012). Ces technologies digitales ont transformé la façon dont nous entrons en contact et interagissons avec l'information (Lantz-Andersson & Säljö, 2014) ainsi que ce que nous pouvons attendre de l'apprentissage en général. Apprendre peut donc se produire à tout moment de façon fluide passant d'un support à l'autre.

Contexte théorique

Comme mentionné précédemment, cette thèse est fondée sur la perspective socioculturelle de l'apprentissage. Dans cette perspective, l'apprentissage est considéré comme étant situé dans un contexte spécifique et parmi les interactions sociales où il a lieu. En d'autres termes, la connaissance et l'apprentissage se manifestent et se développent au cœur des pratiques sociales (Lave & Wenger, 1991; Säljö, 2005). Ainsi, le point focal de ma recherche n'est pas l'individu et son apprentissage personnel mais bien l'entièreté de l'activité comprenant les participants, les outils, et le contexte socioculturel.

Nos actions et nos apprentissages sont également intimement liés aux outils culturels donc nous faisons usage. Par exemple, une personne multipliant deux nombres avec de nombreux chiffres et décimales va s'engager dans des activités très différentes si cette opération doit être faite mentalement, avec un papier et un crayon ou avec une calculatrice. Ainsi, les outils culturels qui nous entourent influencent notre comportement et donc notre apprentissage.

La notion d'appropriation est également clef dans cette perspective de l'apprentissage. L'appropriation consiste à devenir progressivement capable d'utiliser correctement un concept ou un outil (Wertsch, 1998).

Étant donné que l'apprentissage est lié à nos actions et interactions avec d'autres, le langage est considéré comme un outil culturel essentiel. Le langage nous permet de coordonner nos actions et de donner un sens aux contextes dans lesquels nous évoluons (Vygotsky, 1978). Le langage, écrit et oral, est aussi un élément clef de toute entreprise scientifique permettant de formuler des hypothèses, de présenter des résultats et d'argumenter (McGinn & Roth, 1999). Il est donc primordial de mettre en avant la communication scientifique lors de l'apprentissage des sciences (Lemke, 1990; Gyllenpalm, Wickman, & Holmgren, 2010). C'est pour cette raison que ma thèse se concentre sur l'aspect communicatif de l'« ocean literacy ».

Résumé des études

Cette thèse comporte quatre études qui sont décrites ci-dessous. Leur but est de mieux comprendre le rôle et le potentiel de différentes technologies digitales dans l'apprentissage de problèmes environnementaux liés au milieu marin.

Étude I

Publié en tant que:
Fauville G., Lantz-Andersson, A., & Säljö, R. (2013). ICT tools in environmental education: reviewing two newcomers to schools. *Environmental Education Research, 20*(2): 248-283.

Cette étude est une revue de la littérature concernant l'utilisation des technologies digitales dans le cadre de l'éducation à l'environnement. Cette étude débute par une recherche de publications scientifiques sur plusieurs bases de données. Notre recherche se concentre sur des mots clés tels que « environmental education », et « ICT ». Les références citées dans l'ensemble des articles trouvés ont également consultées. Les études trouvées devaient répondre à une série de critères permettant de confirmer leur alignement aux principes d'éducation à l'environnement (UNESCO, 1975, 1977). Dix-neuf études (voir Tableau 4) ont été retenues pour faire partie de notre revue de littérature. Pour chacune d'elles, un compte-rendu de l'objectif, la méthode, le contexte et les résultats de la recherche sont résumés. Ces études recensent différentes technologies (téléphone portable, podcast, réalité augmentée) utilisées dans différents contextes tels qu'en classe, dans des musées ou à l'extérieur.

L'étude I révèle une importante diversité dans les technologies implémentées mais aussi un manque de recherche sur leurs implications pour l'apprentissage. La tendance générale mise en évidence dans ces différentes études révèle un avantage limité ou inexistant de l'utilisation des technologies sur l'apprentissage. Néanmoins, la variété des méthodes utilisées rend toute conclusion difficile à généraliser. Ces activités scolaires sont également souvent mises en place dans l'intérêt de l'étude. Ce qui signifie que ces situations sont la plupart du temps arrangées et ont recours à du personnel supplémentaire comparé à une activité scolaire normale. Cette revue de la littérature conclut ainsi que l'implémentation de technologies pour l'éducation à l'environnement offre l'accès à de nouvelles expériences qu'il n'était pas possible d'avoir dans le cadre scolaire auparavant.

Étude II

Publié en tant que:
Fauville, G., Dupont, S., von Thun, S., & Lundin, S. (2015). Can Facebook be used to increase scientific literacy? A case study of the Monterey Bay Aquarium Research Institute Facebook page and ocean literacy. *Computers & Education, 82*, 60-73.

Cette étude s'attelle à mieux comprendre les opportunités d'apprentissage sur la page Facebook de l'institut de recherche marine Monterey Bay Aquarium Research Institute (MBARI). Pour ce faire, nous avons analysé les commentaires postés sur la page Facebook d'MBARI et interviewé 8 fans de cette page. Nous avons utilisé l'analyse dialogique qui s'intéresse à la construction des normes sociales et à la négociation des interactions à travers le langage oral ou écrit.

Nos résultats démontrent que les interactions entre les fans de la page Facebook et l'administrateur se limitent à une dynamique questions-réponses basée sur des faits scientifiques. Les interactions entre les fans de la page eux-mêmes sont également limitées et ne présentent que très peu de discussion. Les échanges s'enrichissent lorsque le contenu d'un post d'MBARI est partagé par un fan avec ses propres amis Facebook. Dans ce cas, on peut voir émerger de plus riches discussions. Le partage de post semble donc présenter plus d'opportunités pour enrichir les discussions sur le milieu marin. Ceci révèle que la disponibilité de moyen de communication ne suffit pas à voir émerger des discussions permettant l'apprentissage. Il faut que le contexte social soit également adéquat, ce qui semble être le cas pour les commentaires partagés avec ses propres contacts mais pas pour le même post disponible sur une page Facebook avec des membres qui ne se connaissent pas.

Étude III

Publié en tant que:
Fauville, G., Lantz-Andersson, A., Mäkitalo, Å., Dupont S. and Säljö, R. (2016). Digital media as cultural tools: Understanding of and responding to climate change. In O. Erstad, K. Kumpulainen, Å. Mäkitalo, K. C. Schröder, P. Pruulmann-Vengerfeldt, & T. Jóhannsdóttir (Eds.), *Learning across contexts in the knowledge society* (pp. 39–60). Rotterdam, the Netherlands: Sense Publishers.

L'étude III se fonde sur l'idée que les jeunes doivent connaître leur implication dans les problèmes de changements climatiques afin de pouvoir les aborder de façon éclairée. Le concept d'empreinte carbone est abstrait et invisible. Les calculateurs d'empreinte carbone offrent un moyen de rendre visible et de quantifier ce phénomène en laissant l'utilisateur répondre à une série de questions concernant son mode de vie. Cette étude se penche sur une activité scolaire dans le secondaire réunissant des élèves de différents pays. Les élèves utilisent tout d'abord un calculateur d'empreinte carbone et ensuite rejoignent un forum de discussion pour échanger sur leur empreinte carbone. L'utilisation du calculateur d'empreinte carbone débute par la sélection de la région où l'utilisateur habite. Les utilisateurs sont ensuite invités à tenter de prédire si leur empreinte carbone sera au-dessus, en-dessous ou dans la moyenne de leur région. Ensuite, ils répondent individuellement à une cinquantaine de questions concernant leur mode de vie. Finalement, le calculateur donne une valeur en kilogrammes de dioxyde de carbone par an correspondant à l'empreinte carbone de l'utilisateur. Après avoir utilisé le calculateur, les élèves se retrouvent sur un forum de discussion où ils abordent leur empreinte carbone et les façons de la diminuer. Au terme de cette activité, les élèves répondent à un questionnaire concernant l'expérience qu'ils viennent de vivre. Cette étude tente de mieux comprendre comment ce genre de calculateur et de discussions peuvent aider les élèves à réfléchir au problème de changements climatiques liés aux émissions de dioxyde de carbone. Cette étude se fonde sur trois types de données :

- Les prédictions faites par 1722 élèves des Etats-Unis et 248 élèves européens au début de l'utilisateur du calculateur.
- Le contenu de 28 commentaires publiés sur le forum de discussion concernant leur empreinte carbone et la façon de limiter leur impact environnemental.

- Les réponses à deux questions provenant du questionnaire sur l'impact de cette activité scolaire sur leur vision du changement climatique.

Cette étude révèle tout d'abord que les élèves ont tendance à sous-estimer leur empreinte carbone en la prédisant souvent inférieure à la moyenne nationale ou mondiale. Cette tendance est plus forte chez les élèves européens qu'américains. L'analyse des commentaires publiés par les élèves révèle que ceux-ci présentent une structure en 5 parties :

- L'élève commente la prédiction de son empreinte carbone par rapport à la moyenne nationale qu'il a fait au début de l'activité.
- L'élève compare son empreinte carbone avec la moyenne nationale. Dans cette partie, on rencontre de nombreuses expressions de sentiments tels que la joie quand leur empreinte carbone est inférieure à la moyenne et la culpabilité quand celle-ci est supérieure à la moyenne nationale.
- L'élève justifie la différence entre son empreinte carbone et la moyenne nationale en décrivant certains comportements personnels qu'il estime être la raison de cette différence (par exemple, long voyage en avion).
- L'élève propose certaines stratégies pour diminuer son empreinte carbone.
- L'élève traite le concept d'empreinte carbone avec une perspective globale plutôt que locale.

Les données issues du questionnaire révèlent que la majorité des élèves (86,46 pourcents) sont plus enclins à prendre des mesures pour diminuer leur empreinte carbone suite à la participation à cette activité.

Cette étude montre tout d'abord que les élèves abordent cette activité avec une connaissance très limitée et souvent erronée de leur propre contribution aux problèmes de changements climatiques. Cette étude révèle également que les élèves ne se contentent pas simplement de rapporter leur empreinte carbone obtenue grâce au calculateur, mais qu'ils s'engagent également dans une réflexion concernant leur responsabilité et les mesures qu'ils peuvent prendre pour diminuer leur impact. En conclusion, cet outil offre la possibilité de transformer un concept abstrait et peu connu des élèves en un concept qu'il est possible de manipuler et d'influencer en adaptant son comportement.

Étude IV

Publié en tant que:
Fauville, G. (Accepté). Questions as indicators of ocean literacy: Students online asynchronous discussion with a marine scientist. *International Journal of Science Education.*

L'étude IV s'intéresse à une activité scolaire où les élèves conduisent tout d'abord une expérience virtuelle leur apprenant les causes et certaines conséquences de l'acidification de l'océan. Ensuite, ces élèves ont accès à une plateforme digitale nommée VoiceThread où ils regardent la présentation d'un scientifique expliquant les conséquences sociales et économiques de l'acidification de l'océan. Les élèves posent leurs questions au scientifique directement sur la plateforme VoiceThread. Le scientifique pourra ensuite venir consulter les questions et y répondre, créant ainsi une discussion asynchrone avec les élèves. Cette étude a entrepris une analyse thématique (Attride-Stirling, 2001) de 74 questions posées par une soixantaine d'élèves afin de déterminer le genre de raisonnement adopté par les élèves. Après avoir été transcrites, les questions furent codées selon le type de raisonnement qu'elles mettent en évidence. Les différents raisonnements furent ainsi groupés en quatre thèmes :

- Comparaison entre leur propre expérience et les informations reçues du scientifique : les élèves tentent de concilier leur propre expérience avec les informations reçues. Quand ces idées sont en opposition, les élèves peuvent exprimer ce conflit à travers leurs questions.
- Mode de pensée systémique : les élèves considèrent l'acidification de l'océan comme étant un élément du système complexe que représente l'océan. Ces questions montrent que les élèves comprennent qu'une modification entrainera des réactions en chaine dans l'océan.
- Préoccupations environnementales : les élèves réfléchissent aux implications de ces changements environnementaux pour la société et leur communauté.
- Détails à propos de l'expérience scientifique : la présence du scientifique donne aux élèves l'opportunité d'être en contact avec la

culture scientifique. Les questions posées montrent la compréhension des élèves de la nature des sciences et son contexte.

Certaines questions mettent en évidence le déséquilibre entre l'apprentissage des sciences terrestres et marines. Par exemple, certains élèves montrent une bonne compréhension de la photosynthèse se déroulant sur terre mais se retrouvent en terrain inconnu lorsqu'il s'agit de réfléchir au même phénomène en milieu marin.

En conclusion, cette activité semble offrir la possibilité à des scientifiques de se joindre aux conversations scolaires tout en apportant leur propre culture et leur connaissance qui diffèrent de celles des professeurs. De cette façon, les sciences ne sont plus présentées comme une série de faits mais bien comme basées sur l'émergence d'une culture scientifique.

Discussion

La première partie de ma discussion traite des deux premières questions à savoir : « Quel soutien apportent les technologies digitales ? » et « Quels sont les défis présents dans ce contexte ? ».

Tout d'abord, les technologies contribuent à rendre visible l'invisible (tel que l'empreinte carbone dans l'Étude III). Cela donne l'opportunité de manipuler des phénomènes qui autrement restent invisibles et donc difficiles à influencer. Il en va de même pour les scientifiques eux-mêmes, que les technologies peuvent rendre visibles, alors qu'en temps normal, ils ne sont que très peu accessibles au public. Ceci est illustré dans les Études II et IV. De cette façon, les citoyens peuvent comprendre comment la connaissance scientifique est créée par les scientifiques.

Ensuite, les technologies créent un champ d'actions où les utilisateurs peuvent expérimenter, faire des erreurs, voir les conséquences du changement d'un paramètre sur l'entièreté d'un système d'une manière beaucoup plus large que ne le permettent les activités sur papier.

Cela permet par exemple d'observer les conséquences de l'acidification de l'océan sans devoir mettre en place des expériences complexes ou mettre l'environnement en danger. C'est le cas dans l'Étude IV où les élèves conduisent une expérience complexe qui ne pourrait pas être réalisée en classe.

L'Étude II révèle aussi certaines limitations des technologies digitales promouvant la communication. Sur la page Facebook de MBARI, bien que différents moyens soient mis en place pour créer de riches discussions, celles-ci étaient rares et superficielles. Cela démontre que la présence d'opportunités d'échanges est nécessaire mais n'est pas suffisante. Comme exprimé par Jonsson (2004), les opportunités offertes doivent avoir un sens qui n'est pas intrinsèque à la technologie. Ces opportunités pour discuter ne prennent sens qu'en fonction du contexte. Par exemple, dans l'Étude II, l'interaction entre personnes qui ne se connaissent pas n'est pas un contexte propice aux conversations. A l'inverse, la plateforme utilisée dans l'Étude IV, réunissant uniquement les élèves d'une même classe, favorise le développement de discussions, où les élèves n'hésitent pas à mettre en avant les lacunes de leurs connaissances.

Ma discussion traite ensuite la troisième question concernant le rôle que l'« ocean literacy » peut jouer dans les efforts des citoyens pour combattre les problèmes environnementaux marins. Développer l'« ocean literacy » des citoyens est en effet crucial pour différentes raisons. Tout d'abord l'océan nous influence tous où que nous soyons sur la planète et nos comportements influencent à leur tour l'océan. Il est donc important que les citoyens comprennent la manière dont leur mode de vie peut influencer négativement l'océan et par là, les services et produits dont les êtres humains bénéficient. De plus, la connaissance des problèmes environnementaux marins permet aussi de sensibiliser les citoyens à tous les autres problèmes environnementaux sur terre et dans l'atmosphère.

Malgré l'importance de posséder des connaissances sur l'océan, les sciences marines restent rarement étudiées à l'école et les élèves présentent un déséquilibre entre leurs connaissances en sciences naturelles terrestres et marines. Ce phénomène est illustré dans l'Étude IV où les élèves présentent de bonnes connaissances de la photosynthèse se produisant sur terre mais semblent beaucoup moins sûrs de ce phénomène une fois qu'il se produit en milieu marin.

Ma discussion s'achève sur une réflexion à propos des limites de mes recherches. Il est difficile de tirer des conclusions relatives à l'ensemble des technologies digitales, en se basant sur mes recherches qui se limitent à trois plateformes virtuelles. De plus, il est difficile de prédire le futur de ces technologies dans le domaine de l'éducation. Malgré ces limites, ma thèse constitue une contribution importante car elle nous aide à illustrer la façon dont les technologies digitales offrent des conditions nouvelles facilitant l'étude d'un environnement qui est souvent éloigné des citoyens.

En conclusion, les technologies virtuelles ont un rôle important à jouer pour nous aider à nous familiariser avec le milieu marin décrit par Leonardo Da Vinci comme le système circulatoire de notre planète. Cette thèse démontre que les technologies digitales constituent une réelle innovation culturelle permettant d'améliorer l'éducation aux sciences marines.

11. References

Aaen, J., & Dalsgaard, C. (2016). Student Facebook groups as a third space: Between social life and schoolwork. *Learning, Media and Technology, 41*(1), 160–186.

ABC News. (2013). "Mermaids" Mocumentary Stirs Big Ratings for Animal Planet. *ABC News*. Retrieved from http://abcnews.go.com/blogs/entertainment/2013/05/mermaids-mocumentary-stirs-big-ratings-for-animal-planet/.

Adalberon, E., & Säljö, R. (in press). Informal use of social media in higher education: A case study of Facebook-groups. *Nordic Journal of Digital Literacy*.

Adams, L., & Matsumoto, G. (2007). Investigating coastal processes and nitrate levels in the Elkhorn Slough using real-time data. *Oceanography, 20*(1), 200–204.

Adams, L., & Matsumoto, G. (2009). Enhancing ocean literacy using real-time data. *Oceanography, 22*(2), 8–9.

Adams, L., & Matsumoto, G. (2011). The benefits and challenges of using real-time data in the classroom: Perspectives from the students, educators and researchers. *Marine Technology Society Journal, 45*(5), 55–58.

Ahn, S. J. G., Bostick, J., Ogle, E., Nowak, K. L., Mcgillicuddy, K. T., & Bailenson, J. N. (2016). Experiencing nature: Embodying animals in immersive virtual environments increases inclusion of nature in self and involvement with nature. *Journal of Computer-Mediated Communication, 21*, 399–419.

Albayrak, D., & Yildirim, Z. (2015). Using social networking sites for teaching and learning: Students' involvement in and acceptance of Facebook as a course management system. *Journal of Educational Computing Research, 52*(2), 155–179.

Anderson, A. (2013). Climate change education for mitigation and adaptation. *Journal of Education for Sustainable Development, 6*(2), 191–206.

Anderson, J. R., Reder, L. M., & Simon, H. A. (1996). Situated learning and education. *Educational Researcher*, *25*(4), 5–11.

Arnseth, H. C., & Ludvigsen, S. (2006). Approaching institutional contexts: Systemic versus dialogical research in CSCL. *International Journal of Computer-Supported Collaborative Learning, 1*(2), 167–185.

Attride-Stirling, J. (2001). Thematic networks: An analytic tool for qualitative research. *Qualitative Research, 1*(3), 385–405.

Ballantyne, R. (2004). Young students' conceptions of the marine environment and their role in the development of aquaria exhibits. *GeoJournal, 60*(2), 159–163.

Baron, N. (2010). *Escape from the ivory tower: A researcher's guide to making your science matter*. Washington, DC: Island Press.

Beach, R., & O'Brien, D. (2015). Fostering students' science inquiry through app affordances of multimodality, collaboration, interactivity, and connectivity. *Reading & Writing Quarterly, 31*(2), 119–134.

Ben-zvi-Assarf, O., & Orion, N. (2005). A study of junior high students´ perceptions of the water cycle. *Journal of Geoscience Education*, *53*(4), 366–373.

Biernacki, P., & Waldorf, D. (1981). Snowball sampling: Problems and techniques of chain referral sampling. *Sociological Methods and Research, 10*(2), 141–163.

Bingimlas, K.A. (2009). Barriers to the successful integration of ICT in teaching and learning environments: A review. *Eurasia Journal of Mathematics, Science & Technology Education, 5*(3), 235–245.

Bosch, T. E. (2009). Using online social networking for teaching and learning: Facebook use at the University of Cape Town. *Communicatio, 35*(2), 185–200.

Braun, V., & Clarke, V. (2006). Using thematic analysis in psychology. *Qualitative Research in Psychology, 3*(2), 77–101.

Breck, J. (2006). *109 Ideas for virtual learning: How open content will help close the digital divide*. Oxford, UK: Rowman and Littlefield Publisher.

Brody, M. J. (1996). An assessment of 4th-, 8th-, and 11th-grade students' environmental science knowledge related to Oregon's marine resources. *The Journal of Environmental Education, 27*(3), 21–27.

Bruni, C., Chance, R., Schultz, W., & Nolan, J. (2012). Natural connections: Bees sting and snakes bite, but they are still nature. *Environment and Behavior, 44*, 197–215.

Brunvand, S., & Byrd, S. (2011). Using VoiceThread to promote learning engagement and success for all students. *Teaching Exceptional Children, 43*(4), 28–37.

Bulfin, S., Johnson, N., Nemorin, S., & Selwyn, N. (2016). Nagging, noobs and new tricks – students' perceptions of school as a context for digital technology use. *Educational Studies, 42*(3), 239–251.

Büscher, B. (2016). Nature 2.0: Exploring and theorizing the links between new media and nature conservation. *New Media & Society, 18*(5), 726–743.

Cava, F., Schoedinger, S., Strang, C., & Tuddenham, P. (2005). *Science Content and Standards for Ocean Literacy: A Report on Ocean Literacy*. Retrieved from http://www.coexploration.org/oceanliteracy/documents/OLit2004-05_Final_Report.pdf

Cerrone, J. (2013). Protecting the environment is a moral responsibility. *University Wire*. Retrieved from https://search-proquest-com.ezproxy.ub.gu.se/docview/1448668111?accountid=11162

Chan, M., & Pallapu, P. (2012). An exploratory study on the use of VoiceThread in a business policy course. *MERLOT Journal of Online Learning and Teaching, 8*(3), 223–238.

Cheng, C. K., Paré, D. E., Collimore, L. M., & Joordens, S. (2011). Assessing the effectiveness of a voluntary online discussion forum on improving students' course performance. *Computers and Education, 56*(1), 253–261.

Copejans, E., Crouch, F., & Fauville, G. (2012). The European marine science educators association (EMSEA): Towards a more ocean literate Europe. *Current: The Journal of Marine Education, 28*(2), 43–46.

Corner, A., Capstick, S., & Pidgeon, N. (2014). *Public perceptions of ocean acidification: Summary findings of two nationally representative surveys of the British public conducted during September 2013 and May 2014*. (Understanding Risk Research Group Working Paper 14-01). Cardiff, UK: Cardiff University.

Crutzen, P. J. (2002). Geology of mankind. *Nature*, *415*, 23.

Cummins, S., & Snively, G. (2000). The effect of instruction on children's knowledge of marine ecology, attitudes toward the ocean, and stances toward marine resource issues. *Canadian Journal of Environmental Education*, *5*, 305–326.

de Oliveira Roque, F. (2016). Could Pokémon Go boost birding? *Nature, 537*, 34.

Dewey, J. (1897). My pedagogic creed. *The School Journal, 54*, 77–80.

Donnelly, M. K., Kverno, K. S., Belcher, A. E., Ledebur, L. R., & Gerson, L. D. (2016). Applications of VoiceThread(©) technology in graduate nursing education. *The Journal of Nursing Education, 55*(11), 655–658.

Dugartsyrenova, V. A., & Sardegna, V. G. (2016). Developing oral proficiency with VoiceThread: Learners' strategic uses and news. *ReCALL, 29*(1), 59–79.

Dulvy, N. K., Fowler, S. L., Musick, J. A., Cavanagh, R. D., Kyne, P. M., Harrison, L. R., … White, W. T. (2014). Extinction risk and conservation of the world's sharks and rays. *eLife*, 3, e00590.

Dunlap, R., & McCright, A. (2011). Organized climate change denial. In J. S. Dryzek, R. B. Norgaard, D. Schlosberg (Eds.), *The Oxford Handbook of Climate Change and Society* (pp. 144–160). Oxford, UK: Oxford University Press.

Dupont, S., & Fauville, G. (2017). Ocean literacy as a key toward sustainable development and ocean governance. In P. Nunes, L. E. Svensson, & A. Markandya (Eds.), *Handbook on the Economics and Management of Sustainable Oceans* (pp. 519–537). Cheltenham, UK: Edward Elgar Publishers & UNEP.

Earle, S. A. (1995). *Sea Change: A message of the ocean*. New York: Putnam.

Edstrand, E. (2017). *Learning to reason in environmental education: Digital tools, access points to knowledge and science literacy*. Doctoral thesis, University of Gothenburg, Sweden.

Educause Learning Initiative. (2009). *Seven things you should know about VoiceThread*. Retrieved from http://www.educause.edu/library/resources/7-things-you-should-know-about-voicethread

Engstrom, M. E., & Jewett, D. (2005). Collaborative learning the Wiki way. *TechTrends, 49*(6), 12–15.

Ess, C. (2015). New selves, new research ethics. In H. Fossheim & H. Ingierd (Eds.), *Internet Research Ethics*. Norway: Cappelen Damm Akademisk.

EU-Canada-United States Research Alliance. (2013). *Galway statement on Atlantic Ocean cooperation*. Retrieved from https://ec.europa.eu/research/iscp/pdf/galway_statement_atlantic_ocean_cooperation.pdf

EurOCEAN. (2014). *Rome Declaration*. Rome, Italy.

European Marine Board. (2013). *Navigating the future IV Position Paper 20*. Ostend, Belgium: European Marine Board.

Facebook. (2013). *Facebook reports, first quarter 2013 results*. Retrieved from http://investor.fb.com/releasedetail.cfm?ReleaseID.761090

Falls, J. (2012). Five Things you need to know about Facebook's Edgerank algorithm. *Entrepreneur*. Retrieved from http://www.entrepreneur.com/article/223977

Fauville, G., Copejans, E., & Crouch, F. (2013). European marine educators, unite! Europe's quest for a more ocean-oriented society and economy. *The Marine Biologist, 1*, 30–31.

Fauville, G., Hodin, J., Dupont, S., Miller, P., Haws, J., Thorndyke, M., & Epel, D. (2011). Virtual ocean acidification laboratory as an efficient educational tool to address climate change issues. In L. Filho (Ed.), *The economic, social and political elements of climate change* (pp. 825–836). Berlin, Germany: Springer.

Fauville, G., Säljö, R., & Dupont, S. (2013). Impact of ocean acidification on marine ecosystems: Educational challenges and innovations. *Marine Biology*, *160*(8), 1863–1874.

Fletcher, R. (2017). Gaming conservation: Nature 2.0 confronts nature-deficit disorder. *Geoforum, 79*, 153–162.

Fletcher, S., Potts, J. S., Heeps, C., & Pike, K. (2009). Public awareness of marine environmental issues in the UK. *Marine Policy, 33*, 370–375.

Foley, J., Bruno, B., & Tolman, R. (2013). C-MORE science kits as a classroom learning tool. *Journal of Geoscience Education, 61*, 256–267.

Food and Agriculture Organization of the United Nations. (2016). *The state of world fisheries and aquaculture 2016. Contributing to food security and nutrition for all*. Rome, Italy: Food and Agriculture Organization of the United Nations.

Fortner, R. W., & Mayer, V. J. (1983). Ohio students' knowledge and attitudes about the oceans and great lakes. *The Ohio Journal of Science*, *83*(5), 218–224.

Fortner, R. W., & Mayer, V. J. (1991). Repeated measures of students' marine and Great Lakes awareness. *The Journal of Environmental Education*, *23*, 30–35.

Fox, O. H. (2017). Using VoiceThread to promote collaborative learning in on-line clinical nurse leader courses. *Journal of Professional Nursing, 33*(1), 20–26.

Fraser, D. S., Smith, H., Tallyn, E., Kirk, D., Benford, S., Paxton, M., Price, S., & Fitzpatrick, G. (2005). The SENSE project: A context-inclusive approach to studying environmental science within and across schools. In *2005 Conference on Computer Support for Collaborative Learning (CSCL).*

Gee, J. P. (2010). *An Introduction to discourse analysis: Theory and method*. New York and London: Taylor and Francis.

Gelcich, S., Buckley, P., Pinnegar, J. K., Chilvers, J., Lorenzoni, I., Terry, G., … Duarte, C. M. (2014). Public awareness, concerns, and priorities about anthropogenic impacts on marine environments. *Proceedings of the National Academy of Sciences of the United States of America, 111*(42), 1–6.

Gillis, A., Luthin, K., Parette, H. P., & Blum, C. (2012). Using VoiceThread to create meaningful receptive and expressive learning activities for young children. *Early Childhood Education Journal, 40*, 203–211.

Glaser, K. B., & Mayer, A. M. S. (2009). A renaissance in marine pharmacology: From preclinical curiosity to clinical reality. *Biochemical Pharmacology, 78*, 440–448.

Gotensparre, S. M., Fauville, G., McHugh, P., Domegan, C., Mäkitalo, Å., & Crouch, F. (2017). *Meta-analysis of the consultation reports*. Plymouth, UK: EU Sea Change Project.

Gough, A. (2002). Mutualism: A different agenda for environmental and science education. *International Journal of Science Education, 24*(11), 1201–1215.

Greely, T. (2008). *Ocean literacy and reasoning about ocean issues: The influence of content, experience and morality*. Doctoral thesis, University of South Florida, USA.

Green, R. A., Farchione, D., Hughes, D. L., & Chan, S. P. (2014). Participation in asynchronous online discussion forums does improve student learning of gross anatomy. *Anatomical Sciences Education, 7*(1), 71–76.

Green, R. A., & Hughes, D. L. (2013). Student outcomes associated with use of asynchronous on-line discussion forums in gross anatomy teaching. *Anatomical Sciences Education, 6*(2), 101–106.

Greeno, J. (2006). Learning in activity. In K. Sawyer (ed.), *The Cambridge Handbook of the Learning Sciences* (pp. 79-96). New York: Cambridge University Press.

Guertin, L., & Neville, S. (2011). Utilizing Google Earth to teach students about global oil spill disasters. *Science Activities: Classroom Projects and Curriculum Ideas, 48*(1), 1–8.

Guest, H., Lotze, H. K., & Wallace, D. (2015). Youth and the sea: Ocean literacy in Nova Scotia, Canada. *Marine Policy, 58*, 98–107.

Gyllenpalm, J. (2010). *Teachers' language of inquiry: The conflation between methods of teaching and scientific inquiry in science education*. Doctoral thesis, Stockholm University, Sweden.

Gyllenpalm, J., Wickman, P., & Holmgren, S. (2010). Teachers' language on scientific inquiry: Methods of teaching or methods of inquiry? *International Journal of Science Education*, *32*(9), 1151–1172.

Heimlich, J., & Ardoin, N. (2008). Understanding behavior to understand behavior change: A literature review. *Environmental Education Research, 14*(3), 215–237.

Hickey, D. T., Ingram-Goble, A. A., & Jameson, E. M. (2009). Designing assessments and assessing designs in virtual educational environments. *Journal of Science Education and Technology, 18*(2), 187–208.

Hill, J. L., & Nelson, A. (2011). New technology, new pedagogy? Employing video podcasts in learning and teaching about exotic ecosystems. *Environmental Education Research, 17*(3), 393–408.

Hoffman, M., Martos, D., & Barstow, D. (2007). *Revolutionizing Earth System Science Education for the 21st Century: Report and Recommendations from a 50-State Analysis of Earth Science Education Standards*. Cambridge, MA: TERC.

Hou, H. T., Wang, S. M., Lin, P. C., & Chang, K. E. (2015). Exploring the learner's knowledge construction and cognitive patterns of different asynchronous platforms: Comparison of an online discussion forum and Facebook. *Innovations in Education and Teaching International, 52*(6), 610–620.

Ito, M. (2010). *Hanging out, messing around, and geeking out: Kids living and learning with new media*. Cambridge, MA: MIT Press.

Jacobson, A. R., Militello, R., & Baveye, P. C. (2009). Development of computer-assisted virtual field trips to support multidisciplinary learning. *Computers & Education, 52*(3), 571–580.

Jefferson, R. L., Bailey, I., Laffoley, D., Richards, J. P., & Attrill, M. J. (2014). Public perceptions of the UK marine environment. *Marine Policy*, *43*, 327–337.

Jonsson, L. E. (2004). *Appropriating technologies in educational practices: Studies in the contexts of compulsory education, higher education and fighter pilot training*. Doctoral thesis, University of Gothenburg, Sweden.

Jose, J., & Abidin, M. J. Z. (2016). A pedagogical perspective on promoting English as a foreign language writing through online forum discussions. *English Language Teaching, 9*(2), 84–101.

Kacoroski, J., Liddicoat, K. R., & Kerlin, S. (2016). Children's use of iPads in outdoor environmental education programs. *Applied Environmental Education & Communication, 15*(4), 301–311.

Kalman, M., Inchley, J., Sigmundova, D., Iannotti, R. J., Tynjälä, J.A., Hamrik, Z, … Bucksch, J. (2015). Secular trends in moderate-to-vigorous physical activity in 32 countries from 2002 to 2010: A cross-national perspective. *European Journal of Public Health, 25*(2), 37–40.

Kareiva, P. (2008). Ominous trends in nature recreation. *Proceedings of the National Academy of Sciences of the United States of America, 105*(8), 2757–2758.

Kelly, R. P., Foley, M. M., Fisher, W. S., Feely, R. A., Halpern, B. S., Waldbusser, G. G., & Caldwell, M. R. (2011). mitigating local causes of ocean acidification with existing laws. *Science*, *332*(6033), 1036–1037.

Kenny, T., & Gray, N. F. (2009). Comparative performance of six carbon footprint models for use in Ireland. *Environmental Impact Assessment Review*, *29*(1), 1–6.

Kerski, J. J. (2008). The role of GIS in digital earth education. *International Journal of Digital Earth, 1*(4), 326–346.

Kerski, J. J., Demirci, A., & Milson, A. J. (2013). The global landscape of GIS in secondary education. *The Journal of Geography, 112*(6), 232–247.

Ketelhut, D. J., & Nelson, B. (2010). Designing for real-world scientific inquiry in virtual environments. *Educational Research, 52*(2), 151–167.

Kirby, E. G., & Hulan, N. (2016). Student perceptions of self and community within an online environment: The use of VoiceThread to foster community. *Journal of Teaching and Learning with Technology, 5*(1), 87–99.

Klopfer, E., & Sheldon, J. (2010). Augmenting your own reality: Student authoring of science-based augmented reality games. *New Directions for Youth Development, 2010*(128), 85–94.

Klopfer, E., & Squire, K. (2008). Environmental detectives – the development of an augmented reality platform for environmental simulations. *Educational Technology Research and Development, 56*(2), 203–228.

Kollmuss, A., & Agyeman, J. (2002). Mind the gap: Why do people act environmentally and what are the barriers to pro-environmental behavior? *Environmental Education Research*, *8*(3), 239–260.

Kreijns, K., Kirschner, P. A., & Jochems, W. (2003). Identifying the pitfalls for social interaction in computer-supported collaborative learning environments: A review of the research. *Computers in Human Behavior, 19*, 335–353.

Kumpulainen, K., & Sefton-Green, J. (2012). What is connected learning and how to research it? *International Journal of Learning and Media, 4*(2), 7–18.

Lantz-Andersson, A., & Säljö, R. (2014). *Lärande i den uppkopplade skolan* [Learning in the connected school]. Malmö, Sweden: Gleerups.

Lantz-Andersson, A., Vigmo, S., & Bowen, R. (2013). Crossing boundaries in Facebook: Students' framing of language learning activities as extended spaces. *Computer-Supported Collaborative Learning, 8*, 293–312.

Latour, B. (1999). *Pandora's hope. Essay on the reality of science studies*. Cambridge, MA: Harvard University Press.

Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge, UK: Cambridge University Press.

Lemke, J. L. (1990). *Talking science: Language, learning, and values*. Norwood, NJ: Ablex.

Le Monde. (2011). La navigatrice Florence Arthaud a frôlé la noyade au large de la Corse [The navigator Florence Arthaud came close to drowning off Corsica]. *Le Monde*. Retrieved from http://www.lemonde.fr/sport/article/2011/10/30/la-navigatrice-florence-arthaud-a-frole-la-noyade-au-large-de-la-corse_1596188_3242.html

Lim, C. (2008). Global citizenship education, school curriculum and games: Learning mathematics, English and science as a global citizen. *Computers & Education, 51*(3), 1073–1093.

Littleton, K., & Howe, C. (2009). *Educational dialogues: Understanding and promoting productive interaction*. London, UK: Routledge.

Longo, S. B., & Clark, B. (2016). An ocean of troubles: Advancing marine sociology. *Social Problems, 63*(4), 463–479.

Louv, R. (2005). *Last child in the woods: Saving our children from nature-deficit disorder*. Chapel Hill, NC: Algonquin.

Madge, C., Meek, J., Wellens, J., & Hooley, T. (2009). Facebook, social integration and informal learning at university: "It is more for socialising and talking to friends about work than for actually doing work." *Learning, Media and Technology, 34*(2), 141–155.

Markham, A., & Buchanan, E. (2012). *Ethical decision-making and Internet research: Recommendations from the AoIR Ethics Working Committee.* Retrieved from www.aoir.org/reports/ethics.pdf

McGinn, M. K., & Roth, W. M. (1999). Preparing students for competent scientific practice: Implications of recent research in science and technology studies. *Educational Researcher, 28*(3), 14–24.

McKinley, E., & Fletcher, S. (2010). Individual responsibility for the oceans? An evaluation of marine citizenship by UK marine practitioners. *Ocean and Coastal Management, 53*(7), 379–384.

Meishar-Tal, H., Kurtz, G., & Pieterse, E. (2012). Facebook groups as LMS: A case study. *International Review of Research in Open and Distance Learning, 13*(4), 33–48.

National Oceanic and Atmospheric Administration. (2012). *No Evidence of Aquatic Humanoids Has Ever Been Found.* Retrieved from http://oceanservice.noaa.gov/facts/mermaids.html

National Research Council. (2010). *NOAA's Education Program: Review and Critique*. Washington, DC: The National Academies Press.

National Research Council. (2013). *Next Generation Science Standards: For States, By States*. Washington, DC: The National Academies Press.

Oh, E. G., & Kim, H. S. (2016). Understanding cognitive engagement in online discussion: Use of a scaffolded, audio-based argumentation activity. *International Review of Research in Open and Distributed Learning, 17*(5), 28–48.

Organisation for Economic Co-operation and Development. (2016). *The Ocean Economy in 2030*. Paris, France: OECD Publishing.

Pearce, J. M. (2009). Appropedia as a tool for service learning in sustainable development. *Journal of Education for Sustainable Development, 3*(1), 45–53.

Pelegrí, J. L., & Duró, A. (2013). The oceanic memory of climate: The circulatory system of a living planet. *Mètode*, *77*, 36–43.

Pergams, O. R. W., & Zaradic, P. A. (2006). Is love of nature in the US becoming love of electronic media? 16-year downtrend in national park visits explained by watching movies, playing video games, internet use, and oil prices. *Journal of Environmental Management, 80*(4), 387–393.

Pergams, O. R. W., & Zaradic, P. A. (2008). Evidence for a fundamental and pervasive shift away from nature-based recreation. *Proceedings of the National Academy of Sciences of the United States of America, 105*(7), 2295–2300.

Petersson, E., Lantz-Andersson, A., & Säljö. R. (2011). *Knowing nature through experimentation: Science literacy and the situatedness of knowing.* Paper presented at EARLI Conference 2011, Exeter, UK, August 30 – September 3.

Petersson, E., Lantz-Andersson, A., & Säljö, R. (2013a). Exploring nature through virtual experimentation: Picking up concepts and modes of reasoning in regular classroom practices. *Nordic Journal of Digital Literacy, 3*(8), 139–156.

Petersson, E., Lantz-Andersson, A., & Säljö, R. (2013b). Virtual labs as context for learning: Continuities and contingencies in student activities. In E. Christiansen, L. Kuure, A. Mørch, & B. Lindström (Eds.), *Problem-based learning for the 21st century: New practices and learning environments*. Aalborg, Denmark: Aalborg University Press.

Pew Oceans Commission. (2003). *America's living oceans: Charting a course for sea change*. Arlington, VA: Pew Oceans Commission.

Pew Research Center. (2016). *The politics of climate*. Retrieved from http://assets.pewresearch.org/wp-content/uploads/sites/14/2016/10/14080900/PS_2016.10.04_Politics-of-Climate_FINAL.pdf

Pope John Paul II. (1990). *Message of his Holiness Pope John Paul II for the celebration of the World Day of Peace*. Retrieved from https://w2.vatican.va/content/john-paul-ii/en/messages/peace/documents/hf_jp-ii_mes_19891208_xxiii-world-day-for-peace.html

Pörtner, H. O., Karl, D. M., Boyd, P. W., Cheung, W. W. L., Lluch-Cota, S. E., Nojiri, Y., … Zavialov, P. O. (2014). Ocean systems. In C. B. Field, V. R. Barros, D. J. Dokken, K. J. Mach, M. D. Mastrandrea, T. E. Bilir, … L. L. White (Eds.), *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects: Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. Cambridge, United Kingdom and New York, NY, USA: Cambridge University Press.

Ramasundaram, V., S., Grunwald, A., Mangeot, N., Comerford, & Bliss, C. (2005). Development of an environmental virtual field laboratory. *Computers & Education, 45*(1), 21–34.

Robelia, B. A., Greenhow, C., & Burton, L. (2011). Environmental learning in online social networks: Adopting environmentally responsible behaviors. *Environmental Education Research, 17*(4), 553–575.

Rockström, J., Steffen, W., Noone, K., Persson, Å., Chapin, F. S., Lambin, E. F., … Foley, J. A. (2009). A safe operating space for humanity. *Nature, 461*, 472–475.

Ryoo, K., & Linn, M. C. (2014). Designing guidance for interpreting dynamic visualizations: Generating versus reading explanations. *Journal of Research in Science Teaching, 51*(2), 147–174.

Sadler, T. D. (2009). Situated learning in science education: Socio-scientific issues as contexts for practice. *Studies in Science Education, 45*(1), 1–42.

Sattler, S., & Bogner, F. X. (2016). Short- and long-term outreach at the zoo: Cognitive learning about marine ecological and conservational issues. *Environmental Education Research*, *4622*, 1–17.

Schoedinger, S., Tran, L. U., & Whitley, L. (2010). From the principles to the scope and sequence: A brief history of the ocean literacy campaign. *Current: The Journal of Marine Education*, *Special Report #3*, 3–7.

Schrum, L., Thompson, A., Sprague, D., Maddux, C., McAnear, A., Bell, L., & Bull, G. (2005). Advancing the field: Considering acceptable evidence in educational technology research. *Contemporary Issues in Technology and Teacher Education 5* (3–4), 202–209.

Schönfelder, M. L., & Bogner, F. X. (2017). Two ways of acquiring environmental knowledge: By encountering living animals at a beehive and by observing bees via digital tools. *International Journal of Science Education*, *693*, 1–19.

Selwyn, N. (2009). Faceworking: Exploring students' education-related use of Facebook. *Learning, Media and Technology, 34*(2), 157–174.

Sfard, A. (1998). On two metaphors of learning and the dangers of choosing just one. *Educational Researcher, 27*(2), 4–13.

Shultis, J. (2001). Consuming nature: The uneasy relationship between technology, outdoor recreation and protected areas. *The George Wright Forum, 18*(1), 56–66.

Squire, K., & Klopfer, E. (2007). Augmented reality simulations on handheld computers. *Journal of the Learning Sciences, 16*(3), 371–413.

Starks, H., & Trinidad, S. B. (2007). Choose your method: A comparison of phenomenology, discourse analysis, and grounded theory. *Qualitative Health Research, 17*(10), 1372–1380.

Steel, B. S., Smith, C., Opsommer, L., Curiel, S., & Warner-Steel, R. (2005). Public ocean literacy in the United States. *Ocean & Coastal Management*, *48*(2), 97–114.

Steffen, W., Grinevald, J., Crutzen, P., & McNeill, J. (2011). The Anthropocene: Conceptual and historical perspectives. *Philosophical Transactions. Series A, Mathematical, Physical, and Engineering Sciences*, *369*(1938), 842–867.

Sterman, J. D. (1994). Learning in and about complex systems. *System Dynamic Review, 10*(2–3), 291–330.

Stevenson, R. B. (2007). Schooling and environmental education: Contradictions in purpose and practice. *Environmental Education Research, 13*(2), 139–153.

Säljö, R. (2000). *Lärande i praktiken: ett sociokulturellt perspektiv.* [Learning in practice: A sociocultural perspective]. Stockholm, Sweden: Prisma.

Säljö, R. (2005). *Lärande och kulturella redskap. Om lärprocesser och det kollektiva minnet* [Learning and cultural tools: On processes of learning and the collective memory]. Stockholm, Sweden: Norstedts.

Säljö, R. (2010). Digital tools and challenges to institutional traditions of learning: Technologies, social memory and the performative nature of learning. *Journal of Computer Assisted Learning, 26*(1), 53–64.

Säljö, R. (2011). Learning in a sociocultural perspective. In V. Grøver Aukrust (Ed). *Learning and cognition in education* (pp. 59-63). Oxford: Elsevier

Saljö, R., Eklund, A.-C., & Mäkitalo, Å. (2006). Reasoning with mental tools and physical artefacts in everyday problem solving. In L. Verschaffel, F. Dochy, M. Boekaerts, & S. Vosniadou (Eds.), *Instructional psychology: Past, present and future trends* (pp. 73–90). Oxford, England: Pergamon.

Tarng, W., Change, M. Y., Ou, K. L., Chang, Y. W., & Liou, H. H. (2008). The development of a virtual marine museum for educational applications. *Journal of Educational Technology Systems, 37*(1), 39–59.

Tarng, W., Ou, K. L., Tsai, W. S., Lin, Y. S., & Hsu. C. K. (2010). An instructional design using the virtual ecological pond for science education in elementary schools. *Journal of Educational Technology Systems, 38*(4), 385–406.

Thaler, A. D., & Shiffman, D. (2015). Fish tales: Combating fake science in popular media. *Ocean and Coastal Management*, *115*, 88–91.

The Ocean Project. (1999). *Communicating about oceans: Results of a national survey.* Retrieved from http://theoceanproject.org/reports

The Ocean Project. (2009). *America, the ocean, and climate change: Key findings.* Retrieved from http://theoceanproject.org/reports

The Ocean Project. (2011). *America and the ocean*. Retrieved from http://theoceanproject.org/reports

The Ocean Project. (2012). *America and the ocean: Ocean Acidification*. Retrieved from http://theoceanproject.org/reports

Trope, Y., Liberman, N., & Wakslak, C. (2007). Construal levels and psychological distance: Effects on representation, prediction, evaluation, and behavior. *Journal of Consumer Psychology, 17*(2), 83–95.

Turley, C.M., & Blackford, J. (2005) The other CO2 problem. *Marine Conservation, 6*(10), 11.

United Nations. (2017). *Our ocean, our future: Call for actions*. Retrieved from https://oceanconference.un.org/callforaction

United Nations Educational, Scientific and Cultural Organization (UNESCO). (1975). *The international workshop on environmental education final report, Belgrade, Yugoslavia*. Paris: UNESCO/UNEP.

United Nations Educational, Scientific and Cultural Organization (UNESCO). (1977). *First intergovernmental conference on environmental education final report, Tbilisi, USSR*. Paris: UNESCO.

United States Commission on Ocean Policy. (2004). *An ocean blueprint for the 21st Century*. Washington, DC: U.S. Commission on Ocean Policy.

Uyarra, M. C., & Borja, Á. (2016). Ocean literacy: A "new" socio-ecological concept for a sustainable use of the seas. *Marine Pollution Bulletin, 104*(1–2), 1–2.

Uzunboylu, H., Cavus, N., & Ercag, E. (2009). Using mobile learning to increase environmental awareness. *Computers & Education, 50*(2), 381–389.

Verges, M., & Duffy, S. (2010). Connected to birds but not bees: Valence moderates implicit associations with nature. *Environment and Behavior, 42*, 625–642.

Vetenskapsrådet. (2011). *God forskningssed* [Good research practice]. Stockholm, Sweden: Vetenskapsrådet.

Vygotsky, L. S. (1978). *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.

Vygotsky, L. S. (1986). *Thought and language*. Cambridge, MA: MIT Press.

Vygotsky, L. S. (1997). The instrumental method in psychology. In R. Reiber & J. Wollock (Eds.), *The collected works of L. S. Vygotsky; Volume 3; Problems of the theory and history of psychology*. London, UK: Plenum Press.

Wals, A. E. J., Brody, M., Dillon, J., & Stevenson, R. B. (2014). Convergence between science and environmental education. *Science, 344*, 583–584.

Wang, Q., Woo, H. L., Quek, C. L., Yang, Y., & Liu, M. (2012). Using the Facebook group as a learning management system: An exploratory study. *British Journal of Educational Technology, 43*(3), 428–438.

Wellington J., & Osborne J. F. (2001). *Language and literacy in science education*. Buckingham, UK: Open University Press.

Wertsch, J. V. (1998). *Mind as action*. New York: Oxford University Press.

Wertsch, J. M. (2002). Action research and distributed problem-based learning in continuing professional education. *Distance Education*, *23*(1), 59–83.

Wertsch, J. M. (2007). Mediation. In H. Daniels, M. Cole, & J. V. Wertsch (Eds.), *The Cambridge companion to Vygotsky*. New York, NY: Cambridge University Press.

Wilson, E. O. (1984). *Biophilia*. Cambridge, MA: Harvard University Press.

World Health Organization. (2012). *Availability and consumption of fish*. Retrieved from http://www.who.int/nutrition/topics/3_foodconsumption/en/index5.html

World Wide Fund for Nature (WWF). (2016). *Living Planet Report 2016. Risk and resilience*. Gland, Switzerland: WWF International.

Wrzesien, M., & Alcañiz Raya, M. (2010). Learning in serious virtual worlds: Evaluation of learning effectiveness and appeal to students in the E-Junior project. *Computers & Education, 55*(1), 178–187.

Xiang, X., & Liu, Y. (2016). Understanding "change" through spatial thinking using Google Earth in secondary geography. *Journal of Computer Assisted Learning, 33*, 65–78.