INTERNATIONAL JOURNAL OF SCIENCE EDUCATION, 2017
https://doi.org/10.1080/09500693.2017.1365184

Questions as indicators of ocean literacy: students' online asynchronous discussion with a marine scientist

Géraldine Fauville

Department of Education, Communication and Learning, University of Gothenburg, Gothenburg, Sweden

ABSTRACT

In this article, 61 high-school students learned about ocean acidification through a virtual laboratory followed by a virtual lecture and an asynchronous discussion with a marine scientist on an online platform: VoiceThread. This study focuses on the students' development of ocean literacy when prompted to ask questions to the scientist. The students' questions were thematically analysed to assess (1) the kind of reasoning that can be discerned as premises of the students' questions and (2) what possibilities for enhancing ocean literacy emerge in this instructional activity. The results show how interacting with a scientist gives the students an entry point to the world of natural sciences with its complexity, uncertainty and choices that go beyond the idealised form in which natural sciences often are presented in school. This activity offers an affordable way of bringing marine science to school by providing extensive expertise from a marine scientist. Students get a chance to mobilise their pre-existing knowledge in the field of marine science. The holistic expertise of the marine scientist allows students to explore and reason around a very wide range of ideas and aspect of natural sciences that goes beyond the range offered by the school settings.

ARTICLE HISTORY
Received 21 December 2016
Accepted 4 August 2017

KEYWORDS
ICT & education; scientific literacy; environmental education; ocean literacy

Background

Learning about the ocean

The Ocean, covering more than 70% of our planet, is essential to sustainability of humankind by providing economic, social and environmental benefits (e.g. food, jobs, medical compounds and by regulating the climate). Despite its tremendous value, the ocean currently shows significant signs of change as a result of human activities (e.g. change in temperature, increased acidity, decreased oxygen level, habitat destruction). By destroying the ocean – a system, humans are so dependent upon for their survival – our actions are putting us, along with all the other life forms, at risk.

Many threats to the marine environment are rooted in individual behaviours, and education has a crucial role to play in enhancing young people's awareness of the impact their behaviours have on the ocean and the ocean's impact on them (Cava, Schoedinger, Strang,

CONTACT Géraldine Fauville geraldine.fauville@gu.se Department of Education, Communication and Learning, University of Gothenburg, Pedagogen House B, 15, Laeroverksgatan, Box 300, Gothenburg 40530, Sweden

& Tuddenham, 2005). Promoting this kind of knowledge and awareness can be referred to as attempts to increase people's ocean literacy.

An ocean literate person (1) understands the fundamental concepts about the functioning of the ocean, (2) can communicate about the ocean in a meaningful way and (3) is able to make informed and responsible decisions regarding the ocean and its resources (Cava et al., 2005, p. 5). In order to be ocean literate, a person needs to be acquainted with knowledge at the crossroads of science and environmental education (Payne & Zimmerman, 2010; Strang, DeCharon, & Schoedinger, 2007). For instance, to be considered ocean literate, one needs to understand the nature of scientific inquiry (one of the key outcomes of scientific literacy according to Miller, 1983) in order to be able to evaluate the validity of the knowledge and claims regarding current threats to the ocean. In order to be willing to take responsible action towards the ocean, a person needs to have the motive and skills to cope with the environmental needs (one of the components of environmental literacy according to the UNESCO/UNEP, 1989). Moreover, the marine environmental issues presuppose that people are able to engage in what in the literature is referred to as systems thinking in order to comprehend the complexity of marine issues and in order to be able to reason about how to mitigate threats. As worded by Sterman (1994, p. 291), systems thinking implies

> 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.

Systems thinking is a challenge when it comes to understanding the world, since it requires the ability to connect a range of separate types of knowledge concerning a system and understand how they interact with each other (Ben-zvi-Assarf & Orion, 2005a; Hmelo, Holton, & Kolodner, 2000). As argued by Ben-zvi-Assarf and Orion (2005b, p. 519), this 'understanding is actually what science is all about'. In that respect, natural science education has an essential role to play in supporting students to develop their capacities for systems thinking. Several scholars have investigated how to promote systems thinking, for example, by the use of computer-simulated scenario (Evagorou, Korfiatis, Nicolaou, & Constantinou, 2009; Riess & Mischo, 2010) along with trying to understand how systems thinking skills develop (Ben-zvi-Assarf & Orion, 2005b).

Ocean acidification (OA) is a good example of a marine environmental issue that requires systems thinking as it refers to the on-going increase in acidity and perturbation of the carbonate system in the ocean due to the intake of carbon dioxide (CO_2) from the atmosphere. This change in acidity in the ocean causes complex modifications among the marine species. All these modifications due to OA and other marine environmental changes currently threaten the marine environments.

The importance of ocean literacy has been highlighted at the policy level both in the U.S.A. and in Europe. The U.S. Commission on Ocean Policy (2004) 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). Ten years later, the European Marine Board (2013) elaborated on the concept of ocean literacy:

> Ocean literacy is also a prerequisite for Europe's quest for a more marine-oriented society and economy. In fact, preparing 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. (p. 179)

Despite the recognised importance of an ocean literate citizenry, schools often fail to address marine science, and instead the curricula generally focus on terrestrial natural science (Gotensparre et al., 2017; Schoedinger, Francesca, & Jewell, 2006). A letter from the US National Marine Science Educators Association in response to the first draft of the new science standards in the US (Next Generation Science Standards; NGSS Lead States, 2013) objects to this lack of marine topics in the curriculum:

> the science curriculum presents a strong terrestrial bias that 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.[1]

A similar terrestrial focus in formal science education was reported during a series of consultations with education stakeholders conducted in eight European countries (Gotensparre et al., 2017). Thus, even though the importance of a healthy marine environment for sustainability is acknowledged by different stakeholders, marine science is often left out of the classrooms in Europe and in the U.S. Consequently, the need for an ocean literate population and the lack of marine content in school require research attention. This study focuses on students' development of ocean literacy, when prompted to ask questions to a marine scientist on an online collaborative platform called VoiceThread (www.voicethread.com). This asynchronous discussion took place in the context of an instructional practice, where students were learning about OA by first running a virtual laboratory then listening to an online lecture from the aforementioned marine scientist. The learning activity was developed within the Inquiry to Student Environmental Action project (I2SEA; a collaboration between the University of Gothenburg and Stanford University; i2sea.stanford.edu) that offers interactive digital learning tools relating to climate change and OA.

VoiceThread as a learning tool

The online platform used in the studied activity is called VoiceThread (www.voicethread.com), which is a platform that enables users to upload images, video or documents, to record and save audio, video or text comments and to collaborate around these artefacts. A VoiceThread presentation resembles a PowerPoint presentation, with each slide containing an original media artefact (a document, an image, an audio file, a video file or a mixture of these) that serves as a prompt for discussion. The users can navigate through the slides, stop at any point and record their own audio- or text-based comments.

This feature gives the users the opportunity to discuss or explain information pertinent to the content of the particular slide or presentation.

The use of VoiceThread in instructional practices has been studied in a large variety of settings from early childhood education (e.g. Gillis, Luthin, Parette, & Blum, 2012) to professional education (e.g. Fox, 2017). A wide range of methods has been used to investigate the use of VoiceThread in instructional settings. Researchers have analysed the activity logs (Beach & O'Brien, 2015; Dugartsyrenova & Sardegna, 2017; Oh & Kim, 2016) and field notes (Dugartsyrenova & Sardegna, 2017), they have run focus group (Beach & O'Brien, 2015) and conducted semi-structured interviews (Dugartsyrenova & Sardegna, 2017; Oh & Kim, 2016) and analysing online questionnaire (Dugartsyrenova & Sardegna, 2017; Fox, 2017).

Results from these studies highlight positive outcomes of the use of VoiceThread for instruction, such as promoting students' engagement, enhancing students' motivation and improving their understanding (Gillis et al., 2012). Beach and O'Brien (2015) studied the use of VoiceThread by sixth graders as part of a science inquiry 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 emission. 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 these instructional activities (Fox, 2017; Oh & Kim, 2016). As stated by Ching and Hsu (2013), VoiceThread supports social interaction and provides an environment in which students collaborate in knowledge construction through situated participation.

Talking science

This study is rooted in the vision that discourse should be a key element of science and environmental instructional practices. 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 with wider audiences (McGinn & Roth, 1999). In order to provide the coming generations with skills that enable them to understand and take active part in the societal scientific discussions, 'talking science' (Gyllenpalm, Wickman, & Holmgren, 2010; Lemke, 1990) needs to be a central activity in school as well. As noted by Osborne (2002, p. 208), a central goal of science education is to 'help students to use the languages of science to construct and interpret meaning'. But engaging in scientific discourse is challenging for students as it requires not only an understanding of how claims, definitions and explanatory models are developed and expressed in science (Gyllenpalm et al., 2010). In addition, talking science requires an ability to apply concepts in a relevant way in discourses and in their thematic patterns (Lemke, 1990). In that respect, a key focus of science education is to support students in the attempts to develop arguments and explanations and, in addition, to formulate relevant questions (Wellington & Osborne, 2001).

The importance of promoting students' abilities to ask relevant and interesting questions has been advocated by UNESCO (1981) by arguing that '[t]rue learning is characterized not so much by the answering of questions as by the asking of them' (p. 31, my translation). The activity of asking questions offers an opportunity for students to develop their understanding and their ability to properly use concepts related to specific domains. The act of formulating questions is a very complex process, which presupposes that students take an active stand in relation to the ideas that have been presented and try to combine them with their pre-existing knowledge (Chin & Osborne, 2008). If these ideas do not match, and cannot be reconciled, raising questions around the discrepancy becomes an efficient strategy to solve the issue (Wickman, 2004). When a student struggles with various ideas that do not fit together and formulates questions to address this gap, he or she engages in an inquiry process. Inquiry, in Dewey's terms (1938, pp. 104–105), implies 'the controlled or directed transformation of an indeterminate situation into one that is so determinate in its constituent distinctions and relations as to convert the elements of the original situation into a unified whole'. Formulating questions also offers a unique opportunity to summarise ideas by providing a brief account of the context in which the questions emerged and need to be understood. This way of summarising information through questions has been argued to be an efficient learning tool (Koch & Eckstein, 1991). Along with the other advantages cited above, previous research has shown that questions may introduce students to the process of creating hypothesis and prediction (Chin & Brown, 2002). Finally, questions have also been proven to be an important resource for formative assessment (Bell & Cowie, 2001). For teachers, questions offer a unique insight into students' understanding, and knowledge of the concepts discussed (Chin & Osborne, 2008), and for the students, questions can help direct their own learning and monitor their understanding (Osborne & Wittrock, 1983, 1985).

Research aim

The aim of this study is to explore how an instructional activity organised around an asynchronous discussion between a marine scientist and students could serve as a means of promoting ocean literacy in an instructional setting. The focus has been on the questions the students raise after having used a virtual lab and having participated in an online lecture with a marine scientist on issue of (OA). The following research questions have guided the research to be reported:

- 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 this kind of tool-mediated activities in instruction?

Theoretical framing of the study

This study is underpinned by a sociocultural perspective where learning, is seen as emerging from social interaction with other people and with the cultural tools that are available in a specific context (Vygotsky, 1978). From such a perspective, communication and collaboration are regarded as essential components in the learning processes situated in the cultural and social practices (Lave & Wenger, 1991; Säljö, 2005). The situated nature of knowledge suggests that learning cannot be isolated from the environments 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)

For this study, this means that we, when analysing the students questions, include the context and the cultural tools used in the activity and consider how they mediate understanding. As described by Säljö (2010)

> why these technologies are so significant is that they affect the manners in which society builds up and provides access to social memory, that is, the pool of insights and experiences that people are expected to know about and to make use of. (p. 56)

In other words, the cultural tools are an externalisation of human knowledge and expressions of the collective learning, inviting specific ways of thinking and working.

A central idea in the sociocultural perspective is that people develop through participation in cultural activities with more knowledgeable participants. For example, students are able to perform a certain range of tasks on their own, but they are able to manage more complicated tasks when collaborating with more knowledgeable peers, such as illustrated by the students' interaction with a researcher in this study. The concept *zone of proximal development* formulated by Vygotsky (1978) articulates such a view of learner's competences when engaging in independent problem solving, on the one hand, and, on the other hand the potential development that may appear when supported by and/or collaborating with more skilled peers.

An added central assumption of this study is the emphasis on language that serves as a system of resources for making meaning in a given context (Lemke, 1990). Furthermore, our behaviours interact with our understanding of the situation as it is mediated by language. In this context this means that learners need to master a specialised language to make informed meanings in the context of science. Natural sciences (as all sciences) have developed a specific discourse that is central to master in order to accurately participate in discussions in scientific contexts. Being familiar with the semantics of a term in a scientific context is crucial for becoming a participant in the activity in question. In this perspective, practices of questioning, as studied here, can be regarded as significant elements of promoting reasoning, since such activities are situated at the intersection between previous experiences and the newly acquired information and insights encountered in instructional practice.

Research context

In order to understand the context of this study, a brief presentation of the complete instructional activity will be provided.

The learning activity, developed as part of the I2SEA project, included two steps. First, the students were introduced to the marine environmental issue of OA through a virtual laboratory (http://i2sea.stanford.edu/AcidOcean/AcidOcean.htm). They followed a predesigned experiment protocol to virtually grow sea urchin larvae in water with two different levels of acidity, and they measured the growth rate of the larvae in these two conditions. The first activity implied that students observed how the larvae raised in higher acidity water grew slower. The virtual laboratory (Figure 1) is a simplified version of an experiment that was run at the Sven Lovén Centre for Marine Infrastructure - Kristineberg, at the University of Gothenburg.

In the second activity, the students watched an online lecture, hosted on the VoiceThread, by the lead scientist of the experiment mentioned above (Figure 2). The scientist uploaded a PowerPoint slideshow onto VoiceThread and added his audio comments on each slide. He created multiple copies of this presentation so that each class would receive its own link to a private copy of his online lecture.

In the lecture the scientist makes connections with the virtual experiment the students conducted in the previous step and the original experiment, which the virtual experiment is based on. He also placed the results of the experiment (sea urchin larvae growing slower in water with higher acidity) in a social and economic context. This presentation covers the following topics:

- The different steps of the scientific methods are presented
- Reminding students of the experiment they had just run virtually
- Presentation of a similar scientific experiment conducted by his team
- Making explicit 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 ocean acidification
- Explaining the impact of carbon dioxide emissions caused by human activities
- Reflection on our own responsibility in the context of 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

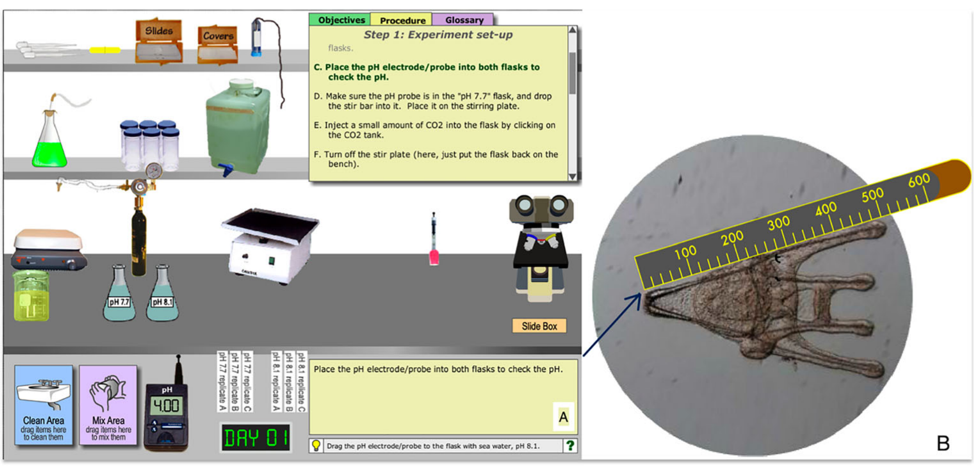

Figure 1. Screenshots of the virtual lab. Screenshot A (left side) presents the virtual lab bench where students conduct their experiment of growing sea urchin larvae in sea water with different level of acidity. Screenshot B (right side) presents a later step when students slide a virtual ruler next to the arm of the larvae in order to measure and compare the growth rate in different conditions of acidity.

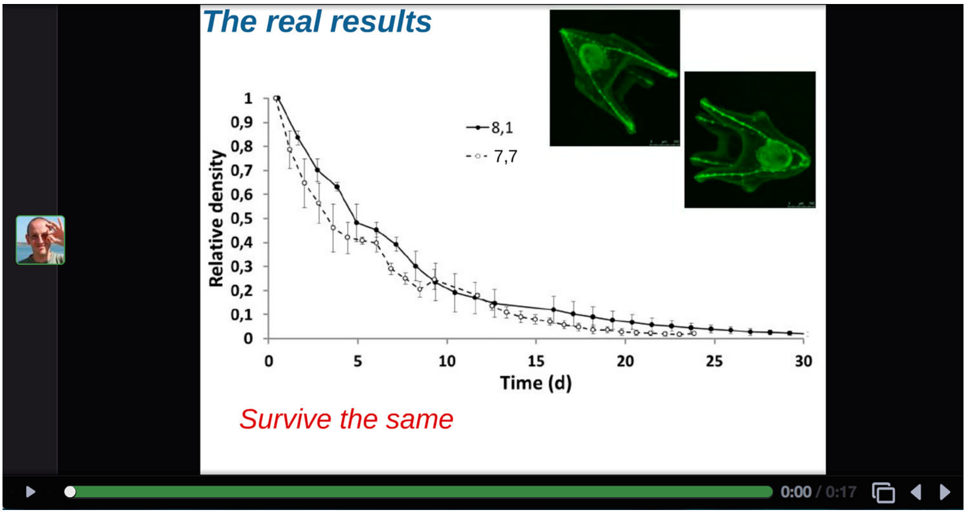

Figure 2. Screenshot of a slide from the VoiceThread presentation.

function where users can embed their comments directly in a chosen slide. The students can thus 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 3). Later on, the teachers informed the scientist that the students had posted their questions. The scientist would then go back to his VoiceThread and could easily see the slides on which the students had added their questions. The scientist could listen to or read the students' questions and record his replies. The teachers would let the students know that the answers to their questions were available on their copy of the VoiceThread. In this way, the students and the scientist engaged in an asynchronous discussion through the VoiceThread platform.

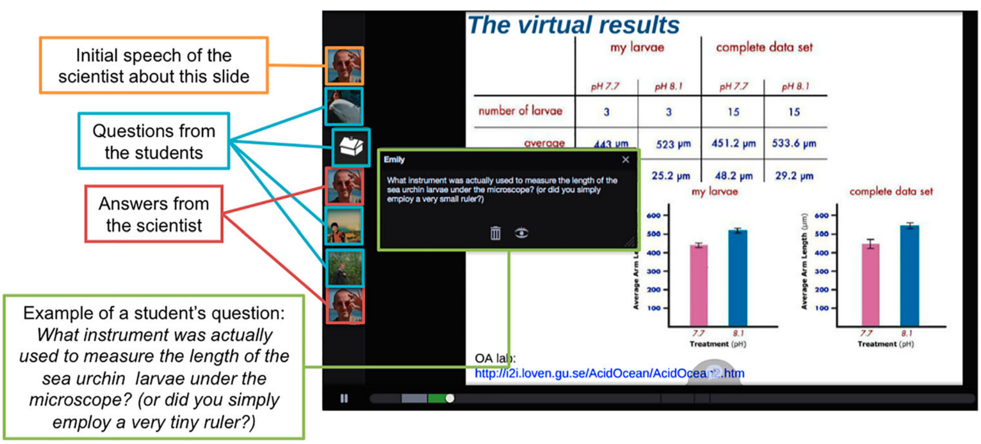

Figure 3. Screenshot presenting a slide from the interactive presentation with the icons corresponding of the users leaving a questions or a comment.

Data analysis

Three highs school classes in two U.S. schools, in total 61 students, participated in this instructional activity as part of their regular class practices (Table 1) in October 2013. The activity lasted for about two weeks in each class.

After completion of the learning activities in the three classes, the initial talk of the scientist from each slide, as well as the students' questions and the scientist replies, were logged on a Word document, making it easier for the researcher to navigate between the different questions and replies from all participants. The students' questions were numbered according to their position in the VoiceThread.

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). In this study, the themes of interest were based on how students related to OA, that is, what premises they used for their reasoning, and how they negotiated their understanding of the marine environmental issue in relation to their pre-existing familiarity with the topic and to new information provided by this instruction activity.

The analysis focused on the data corpus including 74 questions formulated by the students (17 questions from the classes in Illinois and 57 questions from the class in California). The data corpus was transcribed in a Word document to facilitate the manipulation and navigation through the data. As described by Attride-Stirling (2001), the thematic analysis begins with an immersion in the data corpus by repeated reading while looking for patterns related to how students conceive OA in relation to their pre-existing knowledge and the information provided in this activity. After becoming familiar with the data, each question was annotated with a couple of words capturing the main topic addressed. This process helped the researcher to discover recurrent patterns. As the annotating step unfolded, questions revealing similar topics were gathered and labelled under the same code. For examples the two following questions, '`Why did you choose to use sea urchin?`' and '`Did your team develop this type of program to measure, or it is widely used in the scientific community?`' were categorised under the code Research method. The next step in the process implied gathering codes under overarching themes. Table 2 presents the 16 codes that were grouped into 5 themes, 4 of which were kept as the focus of this study.

Finally, the questions were analysed and interpreted in accordance with the emerging themes. For example, for a question placed under the theme 'Systems thinking' the analysis focused on how the student was able to address the issue of OA in relation to a network of cause and consequences. The excerpts presented below illustrate each central theme and analyse some of the students' questions in relation to these themes. Finally, to ensure that relevant interpretations of the data have been made, the thematic analysis was discussed and critiqued in different research group settings.

Table 1. Number of students participating in the study.

	Location	Subject	No. of students	No. of females	No. 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	

Table 2. The 16 codes emerging from the questions aligned with the five themes.

Codes	Themes
• OA info versus personal experience • Terrestrial knowledge on photosynthesis • Virtual versus real experiment	Comparison between everyday experience and OA information
• Mitigation • OA impact on human society • Adaptation	Environmental concerns
• Impact of OA on marine organisms • Natural selection • Impact of OA on water chemistry	Systems thinking
• Research method • Funding • Further research • Analysis results	Details concerning the experiment
• Job opportunities • Motivation • Path	Career (not the focus of this study)

The research adheres to the ethics code of the Swedish Research Council. It is also conducted in accordance with guidelines established by the Association of Internet Researchers (Markham & Buchanan, 2012). The teachers were informed about the nature of the study and that the data collected would only be used for the purpose of research. The teachers then informed the students about the aim of the study and made them aware that participation was voluntary, and that they could discontinue their participation in this study at any moment. All the names used in the excerpts have been changed.

Results

The thematic analysis showed that the nature of the students' questions could be categorised into four qualitatively different themes, illustrating the different kinds of premises the students invoked in their reasoning made visible through their questions. Thus, the questions include some of the information received during the online lecture, which is integrated with the students' prior knowledge, experiences or ideas. The students relate to certain information from the scientist as the more experienced peer (Vygotsky, 1978), and they use it to take a stand in their further elaborations. The four different themes are summarised in Table 3. As mentioned earlier, there were also other questions dealing with the career of the researcher (e.g. `why did you go into marine biology?`, `Where did you go to school and for how long?`), but they fall

Table 3. The four themes emerging from the thematic analysis of the students' questions.

Themes	Description
Comparison between everyday experiences and 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.

outside the scope of this study. The excerpts below are chosen as illustrative examples of the different categories of questions formulated by students.

Comparison between everyday experiences and OA information

In the first category of questions, 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. A sample of four questions is discussed here to illustrate this category.

Excerpt 1.
Q.70 (oral): `Mr. Squamata, I have a question for you about CO`$_2$`. I was actually at my cousin's house over the week and they told me about how they actually add CO`$_2$` to their aquarium to benefit their fish, but in the ocean, CO`$_2$` leads to armful OA. How and why does this happen?`
Q.20 (written): `On a real microscope how do you measure the distance? It does not seem like there is room to slide a real ruler over the slide.`
Q.40 (written): `Do you think the marine plants benefitting from ocean acidification could help actually absorb some of our CO`$_2$` emissions, maybe help prevent greater ocean acidification overall? Sort of like the idea behind planting trees to offset.`
Q.72 (written): `Is there any way to reduce the amount of carbon dioxide in ocean? Like on ground, the plants can convert carbon dioxide to oxygen. But can the sea plants also absorb carbon dioxide?`

These questions illustrate how students consider how to coordinate their previous knowledge or experiences with the new information encountered during the session they had been involved in. Q.70 is grounded in an observation made by the student in his everyday life; `they told me about how they actually add CO`$_2$` to their aquarium to benefit their fish`. This student struggles to reconcile his own experience of the positive impact of CO_2 in an aquarium with of the information about OA included in the interactive talk and which he had noticed (`"but in the ocean, CO`$_2$` leads to armful OA"`). By posting this question the student displays how he engages with understanding some complex and fundamental concepts related to the ocean, an essential step to developing ocean literacy.

In Q.20, the student is referring to the way they measured the arm length of the sea urchin larvae in the virtual lab prior to the online lecture. In the virtual laboratory, they measure the length by sliding a virtual rule over a microscopic image of the larvae (see Figure 1). The student ends up with a conflict between how the length is measured in the virtual lab and his experiences of physical microscopes (`"It does not seem like there is room to slide a real ruler over the slide"`).

In Q.40 and Q.72, the students reveal their prior knowledge about how terrestrial photosynthesis[2] captures CO_2 and releases oxygen (`"Sort of like the idea behind planting trees to offset"` and `"the plants can convert` carbon dioxide to oxygen"). As the previous questions illustrate, these students take a step beyond the information provided in the lecture and use their previous knowledge to raise questions that build on a parallel to an environmental phenomenon they are familiar with: can organisms absorb CO_2 emissions in the sea in ways that are reminiscent of how trees do this on land?

As demonstrated by these four examples, 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).

Systems thinking

The second category of questions implies that students consider OA as an element of a complex system, where a modification in one component will trigger a chain reaction. The degree to which the students comprehend the complexity of this chain reaction varies greatly as demonstrated by the following questions.

Excerpt 2.
Q.55 (written): Hi! I'm part of Mr. Fox's AP biology class in California. Does ocean acidification also slow down the growth of plants in the ocean such as kelp and seaweed? If not, does ocean acidification affect underwater plants in any other way?
Q.67 (written): Since the enchinoderms are weakened by acidification, has there been any results indicating a growth in their predator's population, since weaker prey means easier predation?
Q.50 (written): Hi Mr. Squamata! What exactly are the consequences of slower sea urchin development on the food chain? Would it increase the number of predators since they would have more vulnerable urchins to eat? Thanks!
Q.44 (written): As this slide highlights, zooplankton like these larval sea echinoderms comprise a fundamental aspect of the food chain, feeding many larger predators, and the length of these animals' larval stage is increasing, do you see their predators reaping any benefits from this, at least in the short term? Or would you deduce that this very increase in predation opportunity would decrease the echinoderm (and therefore plankton) populations so much to negatively impact the predators?
Q.63 (written): Do you have any ideas why ocean acidification affects closely related species in such different ways? Does it possibly benefit the ecosystem as a whole, maybe help the ocean maintain some of its diversity even under environmental pressure since no one phylum would go completely extinct?

In the five questions in Excerpt 2, the students engage with similar modes of systems thinking around OA in an ecosystem perspective. What differs between these questions is the degree in which they expose understanding of the complexity of the system and the interconnectivity between the different elements of the ecosystem.

Q.55 displays an initial systems thinking, where the student wonders about the impact of the decrease in pH ("ocean acidification") on "the growth of plants in the ocean such as kelp and seaweed". This student raises a problem about a simple chain reaction going from the change in pH to the living organisms impacted by the changed conditions. Thus, his question elaborates on and extends the general line of argumentation presented by the scientist by asking about other species.

The formulations in Q.67 and Q.50 imply a more developed understanding of the relations between OA and different species. In these questions, the impact of OA on echinoderms is used as a premise ("Since the enchinoderms are weakened by acidification"). In the continuing reasoning, questions about the next step in the chain reaction are raised, namely the consequences of weaker echinoderms on their predators ("on the food chain" and "growth in their predator's population").

Q.44 shows yet another aspect of developed understanding in this chain reaction by engaging with the idea that this "very increase in predation opportunity would decrease the echinoderm (and therefore plankton) populations so much to negatively impact the predators".

A further interesting case of systems thinking is presented in Q.63, where the student not only understands the complexity of the relationship between the elements of this chain but also considers the possibility that OA could "benefit the ecosystem as a whole". In this way, the student displays an understanding of the fragile balance between the different species of an ecosystem, and the fact that a negative impact on one species could be beneficial to another one. In the questions, students engage in systems thinking to address OA as they raise the connections between different elements of OA, and they display a certain degree of understanding that one modification would have repercussions at other levels of the whole system (Sterman, 1994). This kind of systems thinking and understanding about how factors interact are essential in developing ocean literacy (Cava et al., 2005).

Environmental concerns

The interactive talk with the scientist also gives students a unique opportunity to learn and reflect about the way forward for our society in relation to OA by discussing mitigation or adaptation to these new environmental conditions. The third category includes questions that express an opportunity to develop the third tenet of ocean literacy, the ability to make informed and responsible decision concerning the ocean and its resources.

Excerpt 3.
Q.14 (oral): How would OA affect our life in Woodstock Illinois?
Q.3 (oral): How can how can we stop reverse the acidification of the ocean?
Q.73 (written): Hi Mr. Squamata, I had a question about whether or not it is possible to actually take out the carbon that has built up in the

ocean, and if not, does that mean the best we can hope for in the future is to merely maintain the current ocean ph level, or can we actually work to lower it?
Q.59 (written): Is there any possibility of completely reversing the trend of ocean acidification or are we at a point that we can only try to lessen the effects? If it is still possible to get rid of it, what would be the specific actions that everyone would need to do to help the effort?
Q.35 (written): 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?

The student formulating Q.14 lives inland but still seems to understand that marine conditions may have an impact even in his surroundings, that is, that the population will be impacted by OA as this will happen regardless of where we live. The student wonders "how" OA will affect his community rather than *if* it will. This indicates that the student grounds the question on the premise that the impact of OA will not be limited to coastal regions. Q.73, 3 and 59 engage with the idea of lessening OA. Both Q.73 and Q.3 reveal tensions in students' reasoning about the way forward as they wonder if we can still work to reverse this deterioration of the environment, or if the best we can hope for is to stop the process of acidification that is already on its way.

The student formulating Q.3 wonders how we can stop OA but decides to reformulate his question by using a different verb ("reverse"). The shift from "stop" to "reverse" may be read as a sign of developed understanding that, since OA has already changed the acidity of the water, and already has impacts on marine species, stopping it would not be enough. Reversing the process that is currently underway should be the focus of action. The same uncertainty about the current state of this issue is observed in Q.73 inquiring about a potential removal of the carbon to go back to the earlier level of acidity ("take out the carbon that has built up in the ocean") versus focusing our efforts on maintaining the current level ("the best we can hope for in the future is to merely maintain the current ocean pH level").

The tension linked to the uncertainty about the gravity of this issue is also present in in Q.59. In this question, the student does not hesitate between decreasing OA versus working toward maintaining the current level of pH but wonders if it is even still possible to mitigate OA ("reversing the trend of OA"), or if it is too late for mitigation and instead our actions should focus on adapting to the new situation ("or are we at a point that we can only try to lessen the effects"). This illustrates how students engage in reasoning about the urgency of OA as being a situation that can still be mitigated or something that we should adapt to.

Finally, in the last question Q. 35, it is not even considered how to reverse the situation, but rather the student invokes engineering solutions to adapt the population of living organisms through selection inspired by what happens naturally in the environment

("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").

The questions in Excerpt 3 display an awareness of individual and societal responsibility toward this issue, and the need for change, which implies a developed understanding related to ocean literacy (cf., Mckinley & Fletcher, 2010).

Details concerning the experiment

The questions placed in this category probe into the details of the experimentation in which the students ask for further information to be able to evaluate the validity of the experiment and the results.

Excerpt 4.
Q.6 (oral): How many trials did you run?
Q.8 (oral): how did you get the funds to pay for all your materials?
Q. 11 (oral): what complications did you run into?
Q. 16 (oral): How did you measure the 15% mortality rate?

Q. 6, 8 and 11 all ask for follow-up details concerning the experiment the scientist describes in his lecture, and they are anchored in the students' understanding of the scientific method. Q.6 reveals an understanding of the relevance of the number of trials needed to run a valid experiment when asking "how many trials" were run. Q. 8 displays an awareness of some of the reality of scientific work, namely the need to fund the research and "pay for all your materials". In Q. 11 the student wonders "what complications" the scientist ran into (instead of wondering *if* he ran into any) as if it was clear in his mind that scientific experiments are imperfect human endeavours that always run into some kind of difficulties. Q. 16 goes into the statistical analysis performed and shared by the scientist, by requesting more details about how the scientist came up with the findings he describes. These questions display what students already understand about the nature of science by asking questions about the importance of replicates, the need for funding and the potential problems researchers encounter while performing experiments.

Discussion

This aim of this study is to contribute with knowledge in the field of education and ocean literacy by investigating an instructional activity organised around an asynchronous online discussion on OA between high-school students and a marine scientist hosted on the VoiceThread platform. By looking at the questions raised by the students to the scientist, this study sheds light on (1) what kinds of reasoning can be discerned as premises in the questions formulated by students and (2) what possibilities for enhancing students' ocean literacy in school that can be connected to the activity.

Formulating a question is a demanding task where existing experiences and knowledge have to be transformed in the light of new ideas encountered. It is also at the heart of 'talking science' (Gyllenpalm et al., 2010; Lemke, 1990) that is central for learning science. In other words, prompting students to formulate questions can be seen as a fruitful way of organising learning activities (Lave & Wenger, 1991; Säljö, 2005). Since formulating meaningful and scientifically sound questions is rather challenging, the students' questions can be seen as indicators of their knowledge and reasoning about a certain topic. In this study, it was shown that the students' questions provide insights into how they combine their pre-existing experiences and insights with the information gained during the online lecture ("I was actually at my cousin's house over the week and they told me about how they actually add CO_2 to their aquarium to benefit their fish") while reasoning about OA, and how they were trying to integrate their previous knowledge ("Like on ground, the plants can convert carbon dioxide to oxygen") with what they encountered during this instructional activity. To formulate their questions, students make use of scientific concepts (e.g. photosynthesis, food chain) and display their level of mastery of these concepts ("since weaker prey means easier predation"). These questions thus give clues to understanding the premises on which the students formulate their questions.

An interesting illustration of what can be seen as a zone of proximal development (Vygotsky, 1978) in this context relates to their understanding of the process of photosynthesis that is mainly terrestrial ("Like on ground, the plants can convert carbon dioxide to oxygen"). Here the student obviously is able to point to a potentially relevant process and she/he raises the issue if there is a parallel in the ocean. The example of photosynthesis also illustrates that in teaching of science the terrestrial perspective is primary, and the marine context comes second as already discussed. As demonstrated in this paper, several science concepts essential to becoming ocean literate are part of the students' repertoire of premises. It seems that students need help of a more knowledgeable person to make relevant distinctions related to marine sciences in order to understand the fundamentals of the consequences of ocean acidification. For example, the students display certain insights into photosynthesis but do not make further distinctions with respect to photosynthesis in the ocean ("But can the sea plants also absorb carbon dioxide? "). In that respect, teaching takes the terrestrial perspective for granted and never reaches (or gets as far as) the ocean.

This instructional activity based on VoiceThread, a tool allowing an asynchronous discussion between students and a scientist, presents some unique opportunities for students to develop their ocean literacy. What possibilities the students have to develop their understanding of OA, thus, are intimately linked to their activities with this particular tool which invites a specific way of working. First of all, this activity offers an easy and affordable way to virtually bring valid, up-to-date and cutting edge science to the classroom that is often missing in the school curriculum and in the expertise held by the teachers. But scientists do not only come as more knowledgeable peers in the field of science (Vygotsky, 1978), they also bring an extremely broad range of knowledge and first-hand expertise in their fields. Scientists have knowledge about the science of their field, but beyond that they also have a deep understanding of and experience with how their fields emerged and what kinds of studies lead to the current knowledge. Scientists also have the ability to take a critical look at science itself and explain what the weaknesses of the studies forming the body of knowledge are and what areas where more knowledge is needed. In addition, these experts also understand the implications of their field of research on a global scale and grasp the societal and political consequences. In other words, even a teacher with a strong science training would not be able to offer the level of expertise that a scientist fully emerged in the OA research culture and social context can offer. As demonstrated in this study, the students are aware of the expertise of the marine scientist, and they do not hesitate to tap into the very broad source of knowledge. This brings about students to ask questions on a very broad range of aspects going from the genesis of the science of OA itself (see theme '*Details concerning the experiment*') to the mitigating solutions and even to how science could help our society to adapt to these negative changes (see theme '*Environmental concerns*'.

As discussed earlier, the scientific discourse is an essential component of any scientific endeavour, such as science education. A recent study (Macpherson, 2016) demonstrates how scientists (in this case ecologists) rely on a different argumentative discourse than the one used in school. Scientists based their arguments on causal claims (presenting underlying causes for phenomena), while instructional practices focus more on descriptive (description of phenomena) and prescriptive, that is, claims about what humans should do. Moreover, the critical aspect of the discourse is more salient in the scientists discourse than what is present in the school setting. In this respect, putting students into contact with scientists, regardless of the expertise of the teachers, gives them an opportunity to be in contact with the current scientific discourse and culture. This instructional activity not only brings the students into contact with the causal discourse of the scientist, but it triggers their attempts to engage in this kind of discourse by integrating claims about the underlying cause of a phenomenon in their questioning ("`Or would you deduce that this very increase in predation opportunity would decrease the echinoderm (and therefore plankton) populations so much to negatively impact the predators?`"). This finding is supported by previous research on the use of VoiceThread in science inquiry project, where the same benefit for triggering a more causal-based discourse among students was found (Beach & O'Brien, 2015).

In schools, natural sciences are often presented either as a series of facts or in an idealised form. The complexities and uncertainties of science and scientific practices often remain hidden. Interacting with a scientist gives the students another entry point to the world of natural sciences with its culture, complexity, uncertainty and choices. This gives students a chance to investigate and question the challenges a scientist run into (such as "`what complications did you run into?`").

In other words, this instructional activity organised around asking questions to a scientist on the VoiceThread platform mediates the students' reasoning by giving students a unique opportunity to learn about OA from the point of view of a researcher who is socialised and enculturated into the social practice (Gee, 2008) of research in OA.

While the benefit of school–scientist interaction is described above, one should not forget to recognise that scientists do not always have time to visit school and spend time discussing with students (Falloon & Trewern, 2013). VoiceThread offers a potential solution as the scientist only needs to prepare and record one online lecture that could be reused and distributed widely. The scientist can answer the students' questions when time is available and can even require members of her/his research team to help with this task. This online lecture also has the advantage of providing more time for the students to get acquainted with the topic and reflect on their questions.

Environmental issues such as OA are complex by nature and encompass several aspects that go beyond the science itself. It will be difficult for the students to grasp all the concepts involved by attending to the talk only once (as it is the case in real-time presentation). In this case, students can take time to watch at their own pace, navigate through the presentation, and re-watch problematic parts and reflect on the topic in order to formulate their questions.

In conclusion, this instructional activity offers an affordable way of bringing marine science to the classroom by providing in-depth expertise from a marine scientist. Students get a chance to contextualise and mobilise their pre-existing knowledge that they could apply to the field of marine science. The holistic expertise of the marine scientist in his domain allows students to explore and reason around a very wide range of ideas and aspect of natural sciences that goes beyond the range offered by the school settings.

Notes

1. Taken from a letter written by Craig Strang on behalf of the National Marine Educators Association to NGSS. The letter was never published, but I have had access to it through my engagement in the ocean literacy community.
2. Photosynthesis is a process in which energy from the sunlight is used to convert carbon dioxide (CO_2) and water into glucose and oxygen.

Disclosure statement

No potential conflict of interest was reported by the author.

Funding

The research has been funded by Knut and Alice Wallenberg Foundation, the University of Gothenburg Learning and Media Technology Studio (LETStudio) and of the Linnaeus Centre for Research on Learning, Interaction and Mediated Communication in Contemporary Society (LinCS).

ORCID

Géraldine Fauville http://orcid.org/0000-0001-5462-2591

References

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

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.

Bell, B., & Cowie, B. (2001). The characteristics of formative assessment in science education. *Science Education*, *85*(5), 536–553.

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

Ben-zvi-Assarf, O., & Orion, N. (2005b). Development of system thinking skills in the context of earth system education. *Journal of Research in Science Teaching*, *42*(5), 518–560.

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

Cava, F., Schoedinger, S., Strang, C., & Tuddenham, P. (2005). *Science content and standards for ocean literacy: A report on ocean literacy*. Retrieved March 25, 2015, from http://www.coexploration.org/oceanliteracy/documents/OLit200405_Final_Report.pdf
Chin, C., & Brown, D. E. (2002). Student-generated questions: A meaningful aspect of learning in science. *International Journal of Science Education*, *24*(5), 521–549.
Ching, Y.-H., & Hsu, Y.-C. (2013). Collaborative learning using VoiceThread in an online graduate course. *Knowledge Management and E-Learning*, *5*, 298–314.
Chin, C., & Osborne, J. (2008). Students' questions: A potential resource for teaching and learning science. *Studies in Science Education*, *44*(1), 1–39.
Dewey, J. (1938). *Experience and education*. New York, NY: Macmillan.
Dugartsyrenova, V. A., & Sardegna, V. G. (2017). Developing oral proficiency with VoiceThread: Learners' strategic uses and news. *ReCALL*, *29*(1), 59–79.
European Marine Board. (2013). *Navigating the future IV position paper 20*. Ostend, Belgium: Author.
Evagorou, M., Korfiatis, K., Nicolaou, C., & Constantinou, C. (2009). An investigation of the potential of interactive simulations for developing system thinking skills in elementary school: A case study with fifth-graders and sixth-graders. *International Journal of Science Education*, *31*(5), 655–674.
Falloon, G., & Trewern, A. (2013). Developing school-scientist partnerships: Lessons for scientists from forests-of-life. *Journal of Science Education and Technology*, *22*(1), 11–24.
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.
Gee, J. P. (2008). *Social linguistics and literacies* (3rd ed.). New York, NY: Routledge.
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*(4), 203–211.
Gotensparre, S. M., Fauville, G., McHugh, P., Domegan, C., Mäkitalo, Å., & Crouch, F. (2017). *Meta-analysis of the consultation reports*. EU Sea Change Project.
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.
Hmelo, C. E., Holton, D. L., & Kolodner, J. L. (2000). Designing to learn about complex systems. *The Journal of the Learning Science*, *9*, 247–298.
Koch, A., & Eckstein, S. (1991). Improvement of reading comprehension of physics texts by students' question formulation. *International Journal of Science Education*, *13*, 473–485.
Lave, J., & Wenger, E. (1991). *Situated learning: Legitimate peripheral participation*. Cambridge, MA: Cambridge University Press.
Lemke, J. L. (1990). *Talking science: Language, learning and values*. Norwood, NJ: Ablex Publishing Corporation.
Macpherson, A. C. (2016). A comparison of scientists' arguments and school argumentation tasks. *Science Education*, *100*(6), 1062–1091.
Markham, A., & Buchanan, E. (2012). Ethical decision-making and internet research: recommendations from the AoIR Ethics Working Committee (version 2.0). *Association of Internet Researchers*. Retrieved from http://aoir.org/reports/ethics2.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). Ocean & coastal management individual responsibility for the oceans? An evaluation of marine citizenship by UK marine practitioners. *Ocean and Coastal Management*, *53*(7), 379–384.
Miller, J. D. (1983). Scientific literacy: A conceptual and empirical review. *Daedalus*, *112*(2), 29–48.
NGSS Lead States. (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 Learning*, *17*(5), 28–48.

Osborne, J. (2002). Science without literacy: A ship without a sail? *Cambridge Journal of Education*, *32*(2), 203–218.

Osborne, J., & Wittrock, M. C. (1983). Learning science: A generative process. *Science Education*, *67*, 489–508.

Osborne, J., & Wittrock, M. C. (1985). The generative learning model and its implications for science education. *Studies in Science Education*, *12*, 59–87.

Payne, D. L., & Zimmerman, T. D. (2010). Beyond terra firma: Bringing ocean and aquatic sciences to science teacher education. In A. Bodzin, B. S. Klein, & S. Weaver (Eds.), *The inclusion of environmental education in science teacher education* (pp. 81–96). New York, NY: Springer.

Riess, W., & Mischo, C. (2010). Promoting systems thinking through biology lessons. *International Journal of Science Education*, *32*(6), 705–725.

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

Schoedinger, S., Francesca, C., & Jewell, B. (2006). The need for ocean literacy in the classroom. *The Science Teacher*, *73*(6), 44–52.

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: 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*, 53–64.

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

Strang, C., DeCharon, A., & Schoedinger, S. (2007). Can you be science literate without being ocean literate? *Current: The Journal of Marine Education*, *23*(1), 7–9.

UNESCO. (1981). *Guide de l'Unesco pour les professeurs de sciences* [UNESCO handbook for science teachers]. Paris: Author.

UNESCO/UNEP. (1989). Environmental literacy for all. *Connect*, *15*(2), 1–2.

U.S. Commission on Ocean Policy. (2004). *An ocean blueprint for the 21st century: Final report of the U.S. Commission on Ocean Policy*. Washington, DC: U.S. Ocean Commission.

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

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

Wickman, P. O. (2004). The practical epistemologies of the classroom: A study of laboratory work. *Science Education*, *88*(3), 325–344.