Chapter 49
Virtual Ocean Acidification Laboratory as an Efficient Educational Tool to Address Climate Change Issues

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Abstract As the carbon dioxide concentration in the air is increasing, the oceans are changing: they are getting warmer (global warming) and more acidic (ocean acidification). These threats are very likely to have substantial impacts on marine ecosystems and on terrestrial species that depend on the oceans (e.g. human beings). To prevent the most dramatic consequences of such changes to the climate, citizens need to take collective actions. In that respect, education is a key factor to increase our awareness and understanding of climate change. Within the educational project Inquiry-to-Insight (I2I) we have developed, implemented, and tested Information Communication Technology (ICT) tools addressing the climate change issue with high school students.

One such tool that we have developed is an open access virtual animation and laboratory on ocean acidification (OA). This tool allows students to improve their background knowledge of OA and to become virtual scientists, conducting and analysing research on the effect of ocean acidity on a key and well known marine organism: sea urchin. Our results from a pilot study in two high schools in Sweden and California indicate that the OA I2I activities in particular, and other I2I tools in general, increase students' awareness and understanding of OA.

Keywords Education · Ocean acidification · Virtual laboratory · ICT · Climate change · Scientific method

Introduction

The world's oceans are changing. They are getting warmer but are also becoming more acidic. Since the beginning of industrialization and the use of fossil fuels on a large scale, mankind has emitted 361 gigatonnes of carbon into the atmosphere. Between 1800 and 1999, the ocean has absorbed approximately 155 gigatonnes of

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this carbon (Sabine et al. 2004), making the world's oceans the largest sink of anthropogenic carbon dioxide (CO_2). As CO_2 penetrates seawater, it combines with water to yield carbonic acid, which leads to a drop in pH: a process referred to as "Ocean Acidification" (OA) (Caldeira and Wickett 2003). Since the beginning of the industrial revolution, rising atmospheric CO_2 levels have caused the pH of the oceans to fall by 0.1 unit, corresponding to a 25% increase in acidity. Predictions for the coming century suggest that these changes will accelerate rapidly, and that within a few decades, the oceans will be two to three times more acidic than they are at present (a pH drop of 0.3–0.4 units, Caldeira and Wickett 2003, 2005).

This global change in seawater acidity is a major threat and is likely to have important consequences for marine species and ecosystems (see Doney et al. 2009 for review). The rate of change in seawater pH is 100 times anything seen in the past hundreds of millennia. In this way, marine species in the coming century will find themselves in conditions that their ancestors never have had to face (Ruttiman 2006). It follows that OA will have direct and indirect impacts on humans, since the goods and services provided by the ocean will be affected.

So far this issue has been the little-known "evil twin" of global warming (Richard Feely cited by Savitz and Harrould-Kolieb 2008). However, while some short-term solutions exist for organisms to avoid the temperature increases resulting from global warming (e.g. migration), OA is global and unavoidable for marine species.

Climate change issues need to be considered very seriously and collective actions are of the upmost importance. Three different kinds of environmental behaviour can be adopted by citizens in response to such global threats (Lubell et al. 2007) (1) support for policies designed to decrease global warming risk, (2) environmental political action, (3) engaging in personal sustainable behavior that can have an impact on global warming (i.e. reducing one's "carbon footprint").

Four main factors can stimulate environmental behaviours:

- The major factor is the perception of threat (Lubell et al. 2007); people will be more interested in taking action to deter global warming if they understand the significance of the problem (Mohai 1985).
- Perception of personal influence; people need to believe that their action will make a difference (Mohai 1985).
- Degree of education; studies suggest that better educated individual is more likely to take action to protect the environment (Jones and Dunlap 1992).
- Awareness of the consequences of particular behaviour. Citizens need to understand the benefits of their environmental actions (Lubell et al. 2007).

Education can be directed at, and can presumably have a positive influence on, those four factors. In that respect, education will be of key importance in increasing environmental awareness and understanding for the next generation of citizens, policymakers, and educators. Our educational project Inquiry-to-Insight[1] (I2I) aims to address these issues in a innovative manner.

[1] http://i2i.stanford.edu/.

Inquiry-to-Insight Project

Started in November 2008, the I2I project is a collaboration between Stanford University, California, USA and Gothenburg University, Sweden and their respective marine stations; Hopkins Marine Station and Sven Lovén Center for Marine Sciences, Kristineberg. The I2I project offers an educational programme combining various ICT tools. The I2I concept involves pairing classes from different countries within a private social network. This international collaboration gives students the opportunity to compare views, attitudes, and lifestyles related to environmental issues and to broaden their points of view. Within these discussions, students will explore and compare their differing attitudes and environmental choices, their carbon footprint (thanks to an online animation developed by I2I)[2] and their (self-described) bad environmental habits. Students will work collaboratively on an in-depth investigation related to climate change questions (e.g. food choice, media attention to environmental problems, transport).

A pilot study was conducted, pairing senior students from one school in Sweden and one school in California. The Swedish students are enrolled in a national marine biology programme at Gullmarsgymnasiet, Lysekil. The students from Seaside High School, Seaside, California are members of an advanced biology class.

We describe the initial results of this study in more detail below.

Virtual Scientific Conference

To support the learning context and to clarify students' understanding, interactions between scientists and students are important (Lawless and Rock 1998). Unfortunately, this demands more time and money than schools can typically afford, and more time than most active research scientists can allocate. The virtual conference can be a good alternative to gather scientists and students into a discussion. In that respect, VoiceThread, a multimedia slideshow allowing group conversations, seems to be an effective tool.[3]

During our pilot study, I2I scientist Sam Dupont – a leading researcher at the Sven Lovén Centre for Marine Science studying the biological impacts of ocean acidification – created a 15-min virtual conference on ocean acidification for high school students. Students can have a look at the conference at any time, learn at their own pace, and have ongoing discussions and direct interaction on the topic with other students and I2I team members by leaving questions and comments (audio, video, document, text) through the VoiceThread tool.

A concern was that Swedish students could feel insecure and lack confidence about their use of English in comparison with the Californian students. The ICT

[2] http://i2i.stanford.edu/footprint/footprint.html.

[3] http://voicethread.com.

tools can reveal their full potential by obviating this concern. In fact, ICT tools give Swedish students time to formulate, modify, and improve their comments while interacting with students, teachers, and the I2I staff.

Ocean Acidification Curriculum

An open access curriculum addressing the issue of ocean acidification[4] has been developed by the I2I team. This online curriculum is divided into two parts: an interactive animation presenting ocean acidification background and a virtual lab addressing the question: How does ocean acidification effect sea urchin larval development?

Ocean Acidification Animation

The animation provides an overview of the carbon dioxide emission rising and the consequences of changes in the ocean pH on living organisms. The animation introduces the issue step by step:

1. The explanation of the increase in carbon dioxide in the air through time, related to human activity and its consequences; global warming and ocean acidification.
2. A drag and drop interactive game to compare pH of different liquids and to get familiar with the principles of pH (Fig. 49.1).
3. An interactive graph presenting the pH drop in the ocean and a possible scenario for the near future.
4. Calcification – the process in which the mineral calcium builds up in soft tissue as calcium carbonate, causing it to harden – is a key physiological process for many marine organisms to build a skeleton or shell. It is believed to be one of the processes most affected by ocean acidification (OA). The carbonate chemistry and its link to calcification are described; a simple click on each step provides an in-depth and clear explanation of the reaction. This page describes how a drop in pH in the water can interfere with the calcification process (Fig. 49.2).
5. An interactive model demonstrates how the steps of the calcification reaction would be affected under different future emission scenarios (optimistic, middle ground, pessimistic) based upon actual future greenhouse gas emissions scenarios used by the Intergovernmental Panel on Climate Change (IPCC). Students can time travel between 1895 and 2090, shifting from one scenario to another to see how each chemical of the reaction will be affected, what the resulting pH would be, and how that would be predicted to impact calcification in marine organisms (Fig. 49.3).

[4]http://i2i.stanford.edu/CarbonLab/co2lab.swf.

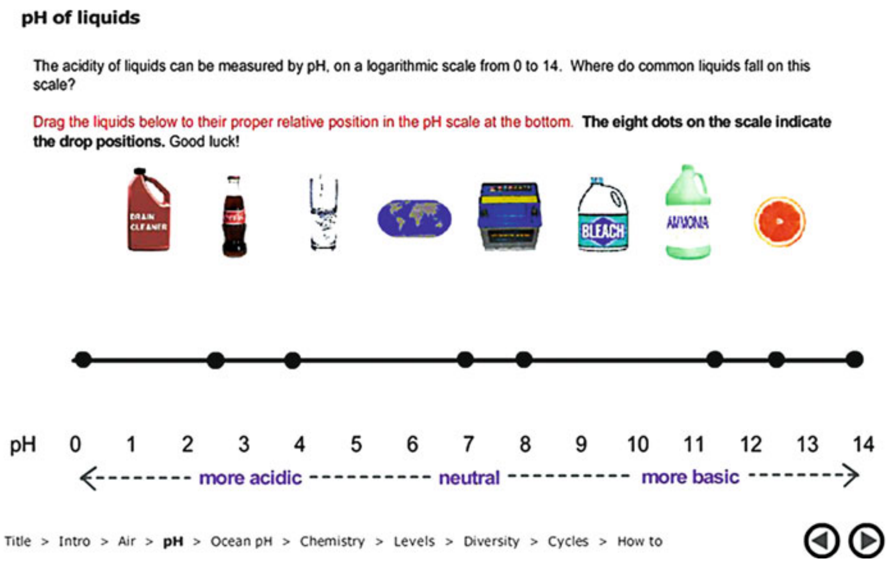

Fig. 49.1 Drag and drop game to introduce the concept of pH through familiar liquids

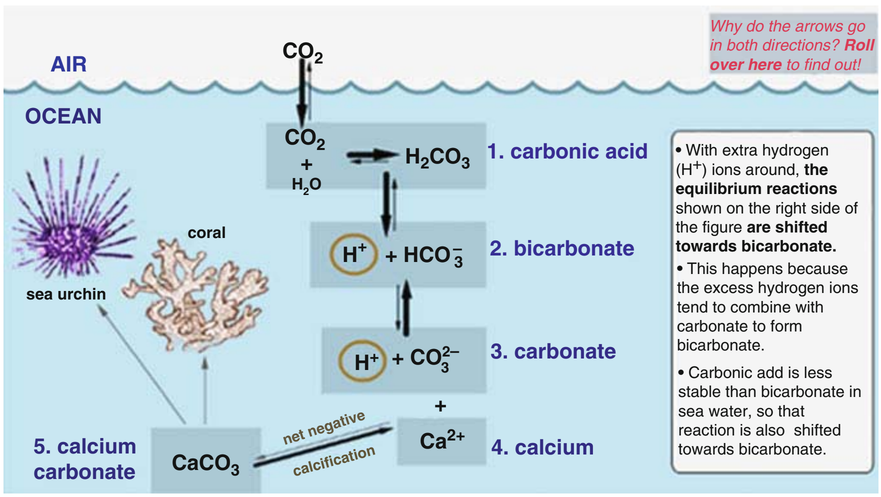

Fig. 49.2 Calcification reaction in the sea water

6. Description of the three main forms of calcium carbonate used by marine organisms to build their skeleton, and which organisms depends on what form.
7. Another drag and drop game on a life tree helps pupils picture the phylogenic relationships between some key marine calcifiers, animal and non-animal.

To illustrate what the consequences of ocean acidification can be on a well-known species, we have used the sea urchin as a model for our virtual OA lab.

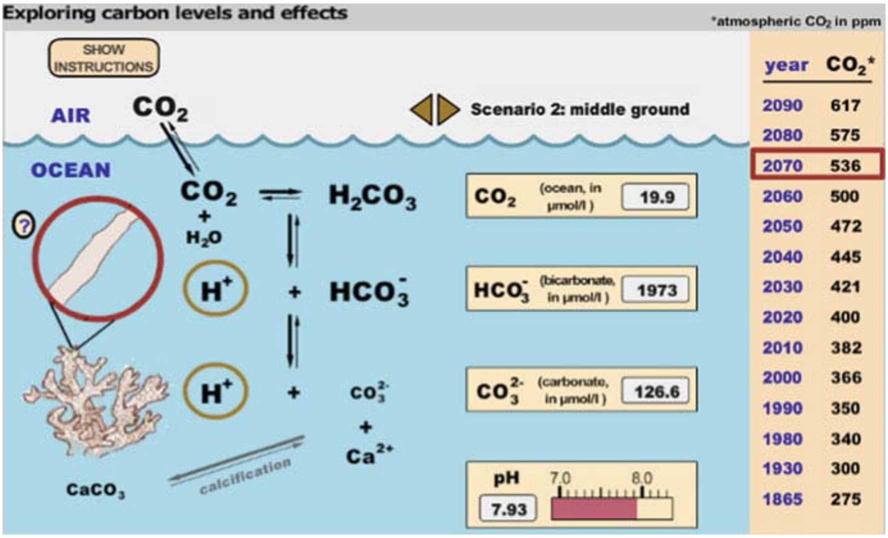

Fig. 49.3 Modifications in the parameters of the calcification reaction through time and under different scenarios; an interactive model

Because of their unique skeleton, sea urchins are one of the most studied organisms in OA field. In particular, their larvae are likely to be strongly impacted by low pH. The complex life cycle of a sea urchin and its magnesium calcite calcium carbonate skeleton development are then described.

Virtual Lab

As students complete the ocean acidification background, they become virtual scientists addressing the question: How does ocean acidification (OA) affect marine life? They perform an experiment to test the impact of OA on sea urchin larval development. They culture sea urchin larvae in 2 different pH conditions (8.1 as a control and 7.7 as the pH value that we can expect for 2100 under a pessimistic CO_2 emissions scenario).

Using an interactive virtual lab, students complete all the procedural steps of the experiment on their lab bench (Fig. 49.4), set up replicate cultures, feed the larvae, make water changes and observe larval development over time.

After 5 days of culture, larvae are mounted on microscope slides for measurement (morphometric) analysis using a virtual microscope. The virtual lab has a database of fifteen individual larvae at each pH (five larvae in three replicates per treatment), and each student measures three randomly chosen larvae at each pH (one larva in each replicate; Fig. 49.5). Each student will thus work on a unique data set. The data the students analyse is actual data addressing this question gathered on

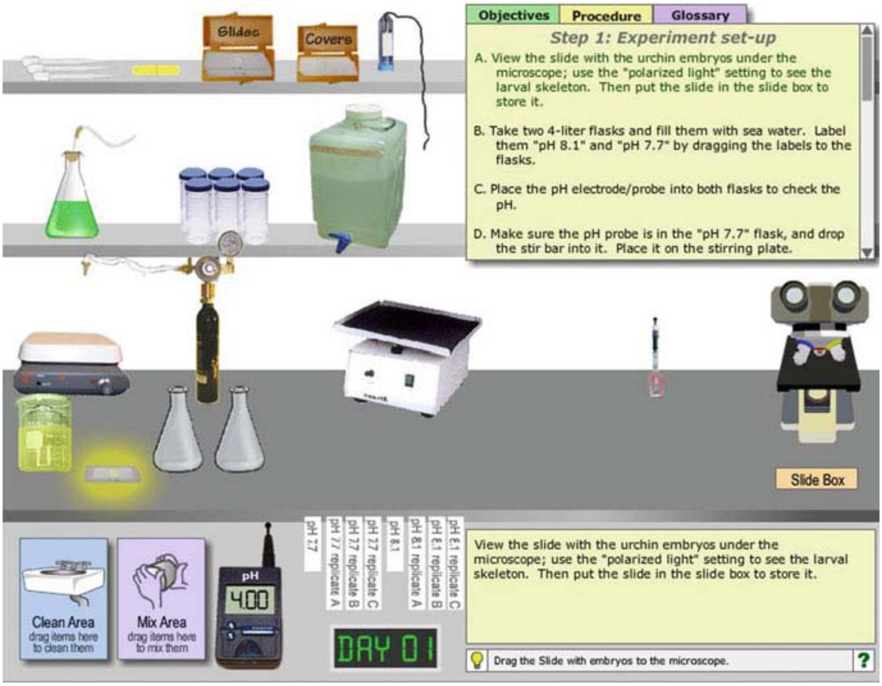

Fig. 49.4 The interactive acidification lab bench

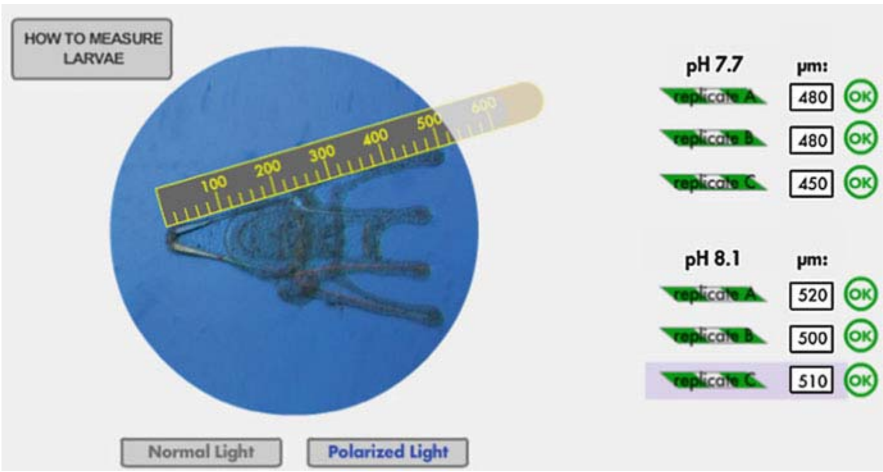

Fig. 49.5 Measurements of the larvae (morphometric analysis). Students align the ruler alongside the larva, and enter their measurement in the boxes on the right. We allow a range of possible measurements around the measurements made by our staff scientists

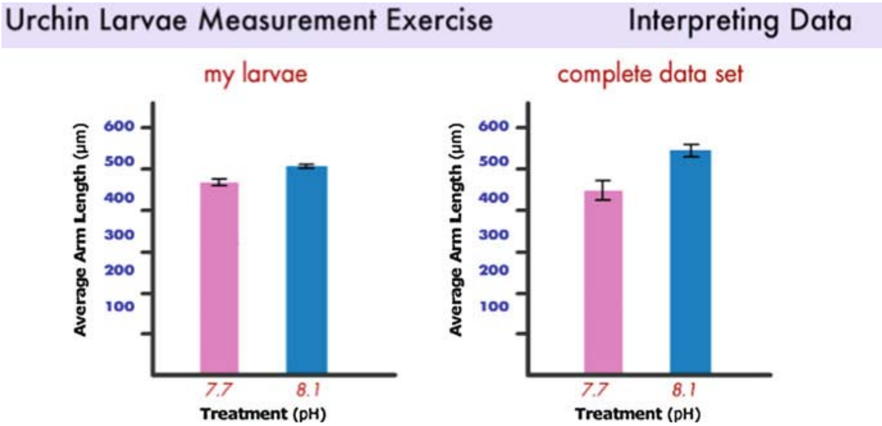

Fig. 49.6 Comparison between results from a subset of data randomly assigned to each student ("my larvae") and the complete data set. In this example, the difference between the treatments is higher in the complete data set, with its increased number of larvae analysed per replicate

the sea urchin *Paracentrotus lividus* by I2I scientists Dupont and Thorndyke, leading researchers at Sven Lovén studying OA impacts on marine life.

After completing the morphometric analysis, students calculate the treatment means using their own unique measurements, and then compare these subsample results with the entire statistical sample (Fig. 49.6).

Students will 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 lab addresses the scientific method and its limitations: an experiment is an abstraction from reality that scientists try to reach. That is why deep critical thinking is essential to get an objective view on the world in general and environmental issues in particular.

Results

In order to evaluate our tools addressing the ocean acidification (OA) issue, students filled in a survey at the beginning and end of the project. The OA survey is designed to assess students' knowledge on this issue and includes six questions. The knowledge score was range from 0 (all wrong answers) to 1 (all right answers).

Our tools significantly increase students' knowledge on ocean acidification. Figure 49.7 compares the results from the pre- and post-surveys from the Californian and Swedish students. While there was no significant difference between Sweden and California (an average score of 0.55; $F = 0.27$, $p < 0.6$), a significant increase in knowledge of 30% ($F = 11.6$. $p < 0.001$) was observed in both countries as a result of exposure to the I2I OA activity (ANOVA II, $F = 3.96$, $p < 0.01$).

Students were also asked to evaluate their level of knowledge with a value between 0 (no knowledge at all) and 1 (best knowledge). The Table 49.1 shows

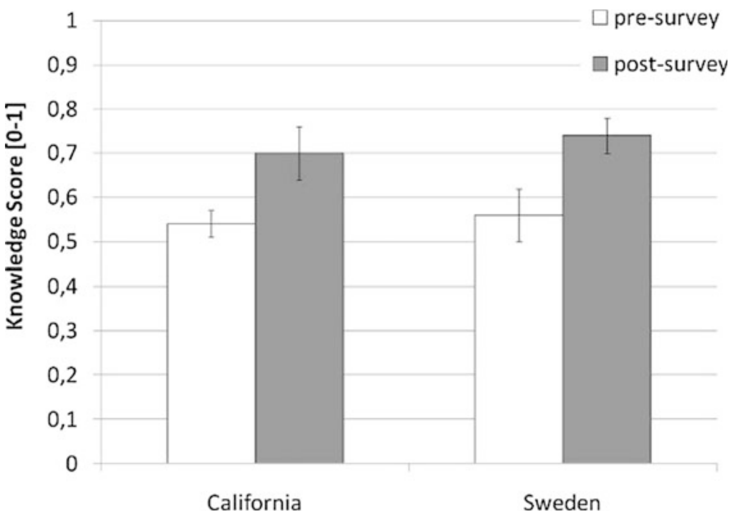

Fig. 49.7 Increase in knowledge (scored between 0 and 1) after the OA animation. Pre-survey in California, n = 15. Pre-survey in Sweden, n = 15. Post-survey in California, n = 9. Post-survey in Sweden, n = 13. The error bars represent the standard error of mean

Table 49.1 Increase in student self-estimation of knowledge on OA before ("pre") and after ("post") undertaking the OA activity. Mean ± standard error of mean

Value	California (pre) (n = 15)	California (post) (n = 9)	p	Sweden (pre) (n = 15)	Sweden (post) (n = 13)	p
[0–1]	0.358 ± 0.052	0.454 ± 0.058	*	0.56 ± 0.04	0.676 ± 0.036	*

that student self-evaluation increases significantly through time by almost 27% in California and by almost 21% in Sweden.

Figure 49.8 illustrates the relation between self-estimation of knowledge and real knowledge on ocean acidification. The symbols (dots and squares) above the line indicates that students' knowledge is higher than their self-estimation of knowledge, which means that they underestimate themselves. The symbols below the line indicate that students overestimate themselves since their knowledge score is under their self-estimation of knowledge.

The majority of our students from both countries underestimate their knowledge before and after I2I participation.

Discussion

We evaluated a group of 30 high school students – 15 in Lysekil, Sweden and 15 in Seaside, California, USA – for their knowledge on the topic of ocean acidification (OA) before and after undertaking our online OA activity. In both groups of

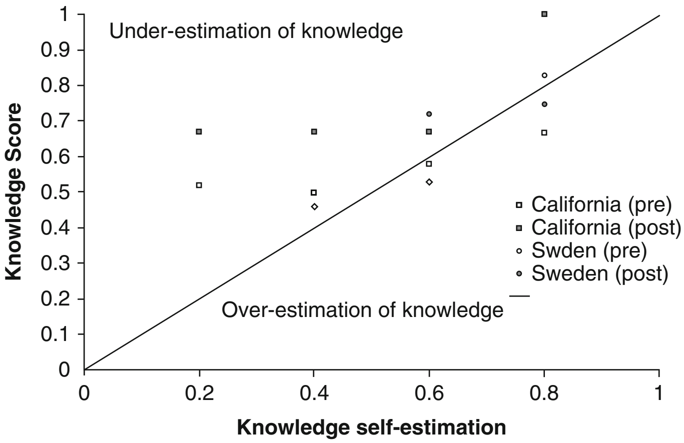

Fig. 49.8 Relation between self-estimation and real knowledge on OA

students, knowledge of OA increased by about 30% as a result of exposure to the I2I OA activity. These preliminary results, showing similarity across the ocean, may indicate the broad applicability of our OA activity across cultures.

Interestingly, students in both the US and Sweden underestimated their knowledge of OA, both before and especially after exposure to the I2I OA activity. The fact that their knowledge increased more than they realized may be seen as a validation of our interactive approach: our activity is designed to be engaging and entertaining, something the students may not generally associate with the learning process. It is possible that they learn more than they realize in this context, something we might refer to as “stealth teaching”. More extensive and complete evaluations will be required to evaluate this possibility.

On the I2I project as a whole, our preliminary results (full evaluations to come) show that student response and enthusiasm surpassed expectations. On both sides, students were eager to meet the sister students. Students show an important interest for the social networking aspect of the I2I project. However, it has been a challenge to bring an educational focus to ICT tools that students use mainly or exclusively in a social context.

By contrast, students participated actively when they were guided in forum discussions related to environmental issues (e.g. “bad environmental habits” or “comparison of students’ carbon footprint”). Moreover, students who never or rarely spoke in class often participated very actively.

Conclusion

Our preliminary results show that the new tools that we developed increase students’ awareness and understanding of environmental issues. This project will also help each school fulfil its goal of education in four different ways.

The scientific dimension is provided by virtual laboratory experiences and virtual discussion with scientists. Laboratory experience is critical for understanding science; lectures and readings do not adequately convey the scientific process (Skolverket 1995; Singer et al. 2005). Yet laboratories are disappearing because they are expensive, require more time than the typical class period, and entail extensive teacher preparation and set-up. Computer-based virtual activities, which simulate (and ideally complement) real lab experiments give the student the flavour of the actual experience. The labs we have developed are made more relevant (Hines et al. 2009), as the students repeat actual experiments on environmental problems, including acquisition and analysis of real data. The students will have the opportunity to discuss such data with the scientists who collected it thanks to VoiceThread discussions.

The critical thinking dimension is provided by teacher-directed (and scientist-validated) analysis of internet content. The web is full of facts about the environment, but this information does not necessarily lead to constructive action since this media often presents contradictory views, even on issues that have a broad consensus in the scientific community (Boykoff and Boykoff 2004; Hart 2007). Making use of resources that are available in the digital world, evaluating the source of this information, and learning to assess apparently conflicting views is a critical part of the learning process. Student understanding of the strengths and limitations of the web will be an important benefit from this project.

The international dimension is a unique aspect of this project. Students in sister schools in Sweden and the US (as well as other countries as the project progresses) will communicate, collaborate, and compare personal, family, and cultural views on attitudes and behaviours related to environmental problems in their respective countries. We believe that this comparative approach, which provides a novel and motivating experience, will remove the narrow perspective where students in each country may feel that their countries' mode of behaviour is the only possible route. This international component broadens the students' view and provides a global approach to shared problems (Cole 2006).

The education dimension is supported by ICT and the peer discussion via social networks within and between classrooms in the different countries. Various studies (Zucker and Light 2009; Myndigheten för skolutvekling 2007) show that students' performance, engagement, and motivation are improved by ICT tools when they are wisely embedded in the curriculum, and that peer discussion increases understanding (Smith et al. 2009). Such findings form an important foundation for our project. We believe this project will be a model for use of those emerging technologies (Hines et al. 2009).

The innovative hypothesis being examined by the I2I project is that sharing views on common environmental problems by social networking will motivate students, enhance learning, and shift student views from an insular to a global one. If validated, this approach would become a paradigm for enriching education and providing global perspectives. The possibilities are limitless, ranging from examination of other shared environmental problems to looking at seemingly intractable differences between countries.

Further Research

In the coming years, our goal will be to:

- Undertake larger-scale and more complete testing of our online activities, including the use of control groups of students exposed to a non-interactive ("paper") acidification curriculum.
- Improve our ocean acidification activity and create new activities on other environmental issues such as habitat issues and mercury toxicity.
- Expand the project to other classes and other countries. I2I project and tools will be translated into Spanish and French.
- Test if the increase in knowledge is associated with a change in behaviour.

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