*Environmental Education Research*, 2013
http://dx.doi.org/10.1080/13504622.2013.775220



# ICT tools in environmental education: reviewing two newcomers to schools

G. Fauville[a,d]*, A. Lantz-Andersson[b,c,d] and R. Säljö[b,c,d]

[a]*Department of Biological and Environmental Sciences, The Sven Lovén Centre for Marine Sciences, University of Gothenburg, Fiskebäckskil, Sweden;* [b]*Department of Education, Communication and Learning, University of Gothenburg, Gothenburg, Sweden;* [c]*The Linnaeus Centre for Research on Learning, Interaction and Mediated Communication in Contemporary Society (LinCS), University of Gothenburg, Gothenburg, Sweden;* [d]*The University of Gothenburg Learning and Media Technology Studio-LETStudio, Gothenburg, Sweden*

(*Received 5 June 2012; final version received 6 February 2013*)

United Nations of Education Scientific and Cultural Organisation's (UNESCO's) founding statements about environmental education (EE) in the 1970s positioned it as a multidisciplinary field of inquiry. When enacted as such, it challenges traditional ways of organising secondary school education by academic subject areas. Equally, according to UNESCO, EE requires various forms of integrated and project-based teaching and learning approaches. These can involve hands-on experimentation alongside the retrieval and critical analysis of information from diverse sources and perspectives, and with different qualities and statuses. Multidisciplinary and knowledge engagement challenges are key considerations for an EE curriculum designed to harness information and communication technologies (ICT) to support and enhance student learning, which also challenge traditional instructional priorities that for example are largely based on textbooks. This review summarises research that has sought to integrate ICT and digital tools in EE. A key finding is that while there is a rich variety of such tools and applications available, there is far less research on their fit with and implications for student learning. The review calls for further studies that will provide models of productive forms of teaching and learning that harness ICT resources, particularly in developing the goals and methodologies of EE in the twenty-first century.

**Keywords:** environmental education and digital media; ICT in classrooms; digital tools; literature review

## Introduction

### *Environmental education*

Covered in the media almost every day, environmental issues are now an important element of the political agenda. As citizens we are expected to understand and contribute to the public debate surrounding such issues that directly affect our future. Environmental education (EE) obviously plays an important role in preparing citizens for participation in such deliberations. It is widely assumed that EE is a

*Corresponding author. Email: geraldine.fauville@bioenv.gu.se

modern initiative arising from the growing concern about the environment that has arisen in recent decades. However, EE is by no means a new arrival in the educational sphere. Influential philosophers, authors and educational thinkers such as Jean-Jacques Rousseau, John Dewey and Maria Montessori, to mention but a few, have drawn attention to the necessity of including issues relating to nature and the environment in schools (Palmer 1998). In the following pages, however, we will limit ourselves to presenting how EE has been shaped as a school subject during the last few decades, as well as discussing certain instructional practices generally considered suitable for this purpose. The final section comprises a review of the literature examining the uses of information and communication technologies (ICT) in EE.

A central element in the political processes responsible for the development of EE is the United Nations Environment Programme, established in 1975. Following this, and under the auspices of United Nations of Education Scientific and Cultural Organisation (UNESCO), the International Environmental Education Programme (IEEP) was launched in Belgrade that same year. The IEEP produced the first set of EE objectives in order to

> develop a world population that is aware of […] the environment and its associated problem and which has the knowledge, skills, attitudes, motivations and commitment to work individually and collectively toward solutions of current problems and the prevention of new ones. (UNESCO 1975, 40)

The list of objectives mentioned includes:

- *Awareness*: to help social groups and individuals acquire an awareness of and sensitivity to the global environment and its allied problems.
- *Attitude*: to help social groups and individuals acquire a set of values and feelings of concern for the environment, as well as the motivation to actively participate in environmental improvement and protection.
- *Skills*: to help social groups and individuals acquire the skills for identifying and solving environmental problems.
- *Participation*: to provide social groups and individuals with an opportunity to be actively involved at all levels in working towards resolution of environmental problems. (UNESCO 1975, 26–27)

During an intergovernmental conference two years later, UNESCO (1977) expanded this list of EE objectives by pointing out that the latter's teaching should have both an international and a local dimension, as well as be characterised by an interdisciplinary approach.

The above-listed EE objectives and principles point to the importance of educating and engaging younger generations in scientific knowledge that is complex but still decisive in the future of society. According to UNESCO, EE instruction should build on collaborative forms of pedagogy and aim to address environmental problems in their complexity, attending to issues such as ethics, risk assessment, public attitudes, politics and legal considerations. In the European Union, EE is now compulsory in primary and lower secondary schools and is clearly presented and specified in many education standards such as the current Swedish curriculum for primary education (Skolverket 2011, 9):

> Through an environmental perspective, they [the students] gain the opportunity both to take responsibility for an environment they can directly influence themselves and to gain a personal approach to global environmental issues. The teaching will shed light on how society functions and the way we live and work can be adapted to create sustainable development.

In other words, EE should promote problem-solving skills, critical thinking and action-oriented insights in relation to central and practical problems that are interdisciplinary in nature. As Stevenson (2007, 146) points out, 'Teaching 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 issues in collaboration with fellow students. This line of argument regarding pedagogy echoes the claims made by scholars studying teaching and learning in the context of so-called socio-scientific issues, that is,. controversial and multidisciplinary issues such as the greenhouse effect, energy use, gene modification of organisms and many others, which are central to citizenship (Sadler, Barab, and Scott 2007; Mäkitalo, Jakobsson and Säljö 2009). Such learning also involves understanding how to approach, formulate and analyse complex issues and where to turn for relevant knowledge, and not merely the reproduction of what is already known (albeit in various different disciplines). In such settings, student-active and problem-based instructional approaches have been argued as providing a suitable context in which to develop knowledge (Ratcliffe and Grace 2003; Khishfe and Lederman 2006). Thus, the pedagogy and philosophy behind EE can be regarded as challenging traditional approaches to schooling, which tend to focus on the acquisition of factual knowledge presented in the classroom by the teacher in order to solve problems with an already existing, single and correct solution (cf. Sfard 1998). Traditional schooling is also highly fragmented in terms of disciplines and is based on abstract problems, with students put in the rather passive position of simply reproducing information and standard procedures (Stevenson 2007).

Where EE is taught today it is most commonly embedded in science or geography curricula. In some countries, however (e.g. Denmark and Finland), EE is taught via an interdisciplinary approach. At the upper secondary level, there may be a range of specialised environmental study courses (Sweden, Belgian Flemish community) in addition to environmental topics being included in subjects such as biology or geography (Stokes, Edge, and West 2001).

In this context, it is important to note that EE is not the only newcomer exerting pressure on established teaching habits and disciplinary structure, with the implementation of ICT also challenging educational practice. Easy access to vast sources of information complements, but also sometimes challenges, traditional media such as textbooks.

### *ICT and education*

The last one hundred years have seen many efforts to implement new technologies in classrooms. These attempts began with radio and film in the early twentieth century, and continued with television, video-recorders and other innovations. Despite the promise of a radical change in instruction, it has been hard to prove that these technologies have had the clear-cut impact that their advocates so vividly maintained (Cuban 1989). The 1970s saw the introduction of computers in schools, and again many proponents of new technology (cf. e.g. Papert 1980) argued that they could potentially transform teaching and learning in quite a dramatic manner. Among the claims made about what this would imply included that technology would:

- Increase communication between students and teachers.
- Increase student motivation.
- Expand the range of pedagogical resources available.
- Help students become experts in actively searching for information rather than passively receiving facts.
- Deepen the understanding of principles and concepts.
- Reduce learner dependency on the teacher (for a review, see Breck 2006; Bingimlas 2009).

Despite these potential advantages, the amount of money invested in introducing computers in schools and the extensive research carried out on this topic, it has been quite difficult to find tangible proof that classroom computers significantly improve student academic performance (Säljö 2010). Taking a socio-cultural-historical theoretical view of communication and learning, it is not surprising to find that again such tools themselves do not bring about change in long-established institutional practices (Vygotsky 1939/1978; Wertsch 1998). Although the assumption that technology can transform instructional practice is part of the same media myth applied earlier, the technology itself is not neutral; new activities and ways of learning built on ICT tools may emerge. It is, for instance, obvious by now that digital technologies have already changed expectations of what it means to learn and know (Säljö 2010). Schools no longer have a monopoly on knowledge, since we now live and learn in what Breck (2006, 115) 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.

Thus, for example, the ability to search for information using increasingly sophisticated search engines of various kinds makes it possible to quickly scan an enormous amount of information. For education, such possibilities are vital given the importance of having up-to-date knowledge and information. Another example is the plethora of virtual tools, associated with different fields, in which the availability of dynamic scenarios allows for more varied forms of interaction with rich learning materials. So even if ICT in itself is not new, it is developing at a rapid pace, while there are also some aspects of digital technology that can be considered "new", at least in relation to education and learning. As digital media and the work they imply are in many ways different from the traditional text-based teaching that education is based on, we will therefore most probably see changes in the ways we organise teaching and learning (Säljö 2010).

As described above, EE and recent digital technologies (e.g. computers, electronic whiteboards, smartphones, tablets) can be regarded as newcomers in the context of schooling, even though they have been around for quite some time. EE and ICT share the potential to support critical and action-oriented problem-based instructional practices. Moreover, as ICT tools and EE both allow for innovation in the education field, EE thus seems a promising setting in which to integrate such tools. This review aims to shed light on such potential by scrutinising the use of ICT in recent EE studies and discussing the results in relation to student learning.

## Digital tools and EE

The purpose of this literature review is to present illuminating examples of how ICT has been used thus far in EE learning activities and to discuss the impacts that digital tools might have on teaching and learning in EE. In order to find suitable papers to include in this review, the authors 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 or science education peer-reviewed journals, such as *Environmental Education Research* and *Research in Science Education*. Finally, the references cited in the papers already identified were reviewed to find additional articles.

All the studies identified needed to fulfil specific criteria in order to be included in the review. Firstly, only those peer-reviewed articles discussing a learning activity employing ICT in some form were selected. Secondly, the learning activities, even if not clearly defined as EE resources by the authors, had to have the potential to be used as such. To establish if this was the case, we consulted the principles of EE outlined by UNESCO (1975, 1977) and created a list of six criteria (see Table 1). To be considered a potential EE activity, we decided that each learning activity should potentially be able to fulfil at least four of the six criteria. Table 1 presents the sixteen papers selected and their alignment to the EE criteria. While the 'yes' and 'no' respectively, mean that we do or do not see the project at stake as potentially able to fulfil a particular EE goal, the question mark indicate that is it difficult to have a clear opinion concerning the potential with the information provided.

However, in order to maintain a global overview of the EE and ICT landscape, it is important to note that the Internet also contains an impressive amount of tools, games and activities dealing with the environment that could (at least some of them) potentially be used in learning activities (Rohwedder 1999). For example, the British Broadcasting Corporation (BBC) created the serious game "Climate challenge", in which the player is the president of a European nation who must tackle climate change whilst staying popular enough to remain in office; these aspects of the game are intended to give some idea of what could happen as the climate changes. The Climate Challenge game aims to help players understand some of the causes of climate change related to the currently accelerating anthropogenic carbon dioxide emission, both to increase user awareness of political and policy dilemmas and to give an insight into the challenges facing the international community. This is only one example of a wide range of free[1] resources available online. Note that some of the tools selected in this review are commercial but the cost impact of their use in formal education is not discussed in the reviewed studies and therefore not examined in this study.

The studies presented below have been categorised according to the location in which the digital resources are used: indoors in the classroom or outdoors during field trips and other similar activities. Sixteen studies are described below, with Table 2 providing an overview which includes the main information about the research reported.

Table 1. Table of the different learning activities included in this study and what EE goals they might potentially reach.

| Activity | Features for being a potential EE learning activity | | | | | | Number of criteria's fulfilled |
|---|---|---|---|---|---|---|---|
| | Criteria based on the EE goals from UNESCO 1975 | | | | Criteria based on additional EE goals from UNESCO 1977 | | |
| | Increase environmental awareness | Acquire value and feeling of concern about environment | Skills to identify and solve environmental problems | Opportunity to participate in environmental solutions | Interdisciplinary | Includes an international and local dimension | |
| Google Earth | Yes | Yes | ? | ? | History, Science, Geography | Yes | 4 |
| Virtual field trip | Yes | Yes | Yes | ? | Civilization, History, Geography, Economy | Yes | 5 |
| Virtual museum | Yes | Yes | ? | ? | Marine science, Nature conservation | Yes | 4 |
| E-Junior | Yes | Yes | Yes | ? | Marine science, Nature, conservation | No | 4 |
| VEP | Yes | Yes | Yes | ? | Limnology, Nature conservation | No | 4 |
| Video podcasts | Yes | Yes | ? | ? | Biogeography, Nature conservation | Yes | 4 |
| EVFL | Yes | Yes | Yes | ? | Geography, Ecology, Scientific investigation, History | No | 4 |
| Acid Ocean virtual lab | Yes | Yes | Yes | ? | Marine science, chemistry, Scientific investigation | No | 4 |
| River city | Yes | Yes | Yes | ? | Scientific investigation, Sociology, Geography, History, Health | No | 4 |

(*Continued*)

Table 1. (*Continued*).

| | Features for being a potential EE learning activity | | | | | | |
|---|---|---|---|---|---|---|---|
| | Criteria based on the EE goals from UNESCO 1975 | | | | Criteria based on additional EE goals from UNESCO 1977 | | |
| Activity | Increase environmental awareness | Acquire value and feeling of concern about environment | Skills to identify and solve environmental problems | Opportunity to participate in environmental solutions | Interdisciplinary | Includes an international and local dimension | Number of criteria's fulfilled |
| QA | Yes | Yes | Yes | Yes | Culture, Language, Nature conservation, Healthy, Economy | Yes | 6 |
| Under control | Yes | Yes | Yes | ? | Environment, Economy, Culture | No | 4 |
| Appropedia | Yes | Yes | Yes | Yes | Sustainability, Poverty reduction, international development, Energy | Yes | 6 |
| Sense project | Yes | Yes | Yes | ? | Scientific investigation, Pollution, Geography | No | 4 |
| ED | Yes | Yes | Yes | ? | Pollution, Scientific investigation, Geography, Health, Environmental regulation | No | 4 |
| TimeLab2100 | Yes | Yes | Yes | ? | Politic, Climate change, | No | 4 |
| Using mobile phone for local environmental awareness | Yes | Yes | Yes | Yes | Social, Pollution, Environment conservation | No | 5 |

Table 2. Table presenting an overview of the different papers reviewed.

| | Targeted audience | Tool | Topics taught | Authors | Research subjects | Research method | Research review |
|---|---|---|---|---|---|---|---|
| Indoor | Elementary school | Virtual museum | Marine ecology and concept of environmental protection | Tarng et al. (2008) | 6 students from 5th and 6th grades. 3 teachers | In-depth interviews and observations | Students engaged. Advantages and challenges for teachers |
| | | E-Junior | Ecology and natural science | Wrzesien and Alcañiz Raya (2010) | 48 students (10–11 years old) | ICT VS traditional learning. Pre- and post-tests, observation | Same increase in knowledge with both treatments |
| | | VEP | Natural and environmental science | Tarng et al. (2010) | 2 grade 3 classes | ICT VS traditional learning. Pre- and post-tests. In-depth interviews | Same increase in memorization and comprehension with both treatments. Critical thinking higher with ICT treatment |
| | Elementary and middle schools | QA | Broad range including culture, ecology, math, English | Lim (2008) | 80 students in primary school | Observations, pre- and post-tests, interviews with teachers and students | Increase in motivation |
| | | | | Hickey, Ingram-Goble, and Jameson (2009) | 4 classes of sixth grade | ICT VS traditional learning, multiple-choice questionnaire on far transfer knowledge | Increase in knowledge slightly higher in ICT treatment |

(*Continued*)

Table 2. (*Continued*).

| Targeted audience | Tool | Topics taught | Authors | Research subjects | Research method | Research review |
|---|---|---|---|---|---|---|
| Middle school | Google Earth | Study history and contexts of the 50 worse oils spills | Guertin and Neville (2011) | No research | No research | No research |
| | River City | Science education with strong multidimensionality and environmental focus | Ketelhut and Nelson (2010) | 5 teachers and 500 students in 7th grades | ICT VS traditional learning. Pre- and post-tests | Same increase in knowledge in both treatments. Higher engagement in ICT treatment |
| | Under Control | Environmental, cultural and economic impact of the construction of dams | Engstrom and Jewett (2005) | No evaluation | No evaluation | No evaluation |
| High school | Acid ocean virtual lab | Ocean acidification, scientific method | Fauville et al. (2011) | 30 students | Pre- and post-tests | Increase in knowledge |
| | | | Petersson, Lantz-Andersson, and Säljö (2011) | 80 high school students | Pre- and post-assignment | Indication of transfer of knowledge |
| Higher education | Virtual field trip | Soil degradation and environmental destruction linked to human civilizations. | Jacobson, Militello, and Baveye (2009) | 15 undergraduate students and undetermined number of students from another class. | Multiple choice questionnaire evaluating recall of the content | Very high % of correct answers |

(*Continued*)

Table 2. (*Continued*).

| | Targeted audience | Tool | Topics taught | Authors | Research subjects | Research method | Research review |
|---|---|---|---|---|---|---|---|
| | | Video podcasts | Biogeography and conservation | Hill and Nelson (2011) | Undetermined numbers of undergraduate students | Questionnaires, focus group. Comparison of assessment results with and without videopodcasts | No difference in average grades. Students more engaged with their learning |
| | | Appropedia | Physics of energy and the environment | Pearce (2009) | No evaluation | No evaluation | No evaluation |
| | | EVFL | Environmental properties and processes of specific landscapes | Ramasundaram et al. (2005) | No evaluation | No evaluation | No evaluation |
| Outdoor | Elemenary and middle schools | Sense Project | Collection and analysis of air pollution data | Fraser et al. (2005) | 1 class of students aged 10–11 and 1 class with students 13–14 | No evaluation | No evaluation |
| | High school and higher education | ED | Complex environmental science investigation | Klopfer, Squire, and Jenkins (2002), Squire and Klopfer (2007), and Klopfer and Squire (2008) | 3 higher education classes and 1 high school class | Observations, video recording | Enthusiasm but failed to reach the goal of construction a valid action plan |

(*Continued*)

Table 2. (*Continued*).

| | Targeted audience | Tool | Topics taught | Authors | Research subjects | Research method | Research review |
|---|---|---|---|---|---|---|---|
| | Higher education | Timelab 2100 | Environmental issues and political implications | Klopfer and Sheldon (2010) | Undetermined number of students | Observations | Connection between scenario presented and personal experience |
| | | Using mobile phones for local environmental awareness | Local environmental awareness | Uzunboylu, Cavus, and Ercag (2009) | 41 students | Pre- and post-tests | Increase environmental awareness |

### *In the classroom*

One of the basic assumptions associated with productive learning is that the content must be meaningful to the learner (e.g. Ramasundaram et al. 2005). In EE, field trips are considered to be a particularly valuable part of the learning experience because they enable first-hand contact with nature. Unfortunately, they are not often a sustainable option for several reasons, such as budget restrictions, time limitations and even in terms of participant security. For educators, the task of teaching topics that are abstract, and sometimes distant from students' everyday realities, is challenging, a fact pointed out in the Tbilisi declaration (UNESCO 1977). New media offer interesting alternatives in the sense that they can be designed to provide opportunities for virtual excursions, explorations and travels in both space and time. Such activities may pave the way for feelings of connectedness and meaningfulness for young learners within the framework of the classroom. Moreover, combining environmental studies with history and geography offers the means to empower students with a better understanding of the temporal and geographical continuum impacting the Earth. Even if virtual excursions and explorations cannot provide the same physical perceptions as would a traditional field trip, they may be able to help students imagine what such a visit to that place or time would feel like (emotionally and physically) and thus be a potentially productive and sustainable alternative to consider seriously. Below, seven examples of projects (Google Earth, virtual field trip [VFT], virtual museum, E-Junior, virtual ecological pond (VEP) and video podcasts, Environmental virtual field trip [EVFL]) will be described. These resources all aim to provide students with such an experience, with ICT employed to visit places and/or times otherwise inaccessible.

#### *Google Earth*

During the BP Deepwater Horizon oil leak, a middle school Earth and Environmental Science teacher decided to study the history and context of past oil spills by introducing his students to the 50 worst such events in history across the globe. The teacher created a Google Earth file named 'Black tides: The worst oil spills in history' (Tryse 2008) linking history, geography and environmental content, with the file providing location, photos, data (type of spill, cause, date, amount of oil) and further resources for each disaster. During the activity, students were mainly asked questions that focused on information recall, but there were also those that required a deeper understanding of the topic. Guertin and Neville (2011) do not mention any evaluation performed on this activity, leaving the reader with little information about the challenges encountered and the learning outcomes. Thus, as will be seen in many studies throughout the review, the implication for the students' learning is not discussed.

#### *Virtual field trips*

Jacobson, Militello, and Baveye (2009) developed their VFT for university courses dealing with the connection between civilisations and soil. The aim of the design was to encourage students to reflect on the fact that overuse of natural resources, which can lead to soil degradation and environmental destruction, has contributed to the collapse of large and influential civilisations.

The location selected for this VFT was the Chinampa zone of the former Lake Xochomilco in southern Mexico City. During the VFT, the learners discover agricultural innovation, how the system of agriculture was originally designed, why it was initially so productive and why it is currently in danger of disappearing. Learners also virtually meet tourists in order to consider the role of visitors in the economy and the preservation of the area. Finally, they are given the chance to discover the environmental decline that has occurred in the basin due to land drainage and urban expansion.

The VFT includes a wide range of media that seems necessary to support the teaching goals. The text acts as a tour guide narrating the story, whereas the maps (present and historical) illustrate geospatial relationships and help users understand how the landscape has evolved over time due to human activities. Moreover, a map-layering tool allows users to obtain a better grasp of the changing relationship between political boundaries, geological landforms and geographical landmarks over time. Finally, the VFT displays animated sequences explaining abstract concepts or images that cannot physically be seen (e.g. long-term and/or underwater processes), as well as short videos of local experts giving their personal perspectives on the topic in their own words. Finally, the Chinampa VFT offers a unique learning opportunity by combining topics including history, world culture and environmental science in a shared tool.

While the authors do not describe any challenges encountered by the students or the teachers using this VFT, they provide interesting information as to what they themselves learned while creating the tool. Among other things, they point out that multimedia is expensive and thus needs to be used where it can have a significant impact.

A pilot version of the VFT was tested at Cornell University on 15 students from two undergraduate courses in soil science, and on four sophomore students in a seminar class focusing on sustainable land. The authors evaluated the learning outcomes of this VFT from three different perspectives.

Firstly, students presented a very high percentage of correct answers (93%) on a multiple-choice questionnaire aimed at evaluating how much they remembered of the content of the VFT.

Secondly, it is well known that critical thinking is a crucial skill in modern society, where the flow of information is hard to evaluate and often quite biased in the sense that it reflects the interests of specific stakeholders, including those associated with environmental issues. It is important for citizens to develop skills with which they can take a stand and engage in critical inquiry into the validity of information presented. Jacobson, Militello, and Baveye (2009, 579) suggest that the VFT might trigger such active and independent thinking, describing that after a classroom discussion:

> A number of students later returned to the VFT to follow-up on a point of discussion, i.e. to verify whether or not a classmate's facts were valid, to look-up something most of the other students thought was interesting, but that they themselves had missed, or to validate information used in their arguments.

In addition, an important goal of EE is to understand that any environmental decision is intimately connected with the socio-economic and political dimensions of society. In many cases, there will be no single and unequivocal solution to environmental dilemmas; suggested solutions will typically have advantages and disadvantages in terms of social development. The analyses revealed that students using the VFT seemed to understand this complexity, since there was no attempt during discussions to solve all disagreements or to reach a single correct solution. Students appeared to accept all opinions that could be logically defended.

In their essays, students seemed to respond very favourably to the environment through comments such as:

> ... I felt as though I was almost in Mexico myself. (Jacobson, Militello, and Baveye 2009, 578)

> I learned more and was more engaged than I thought I might be. I also think that touring the website allowed me to remember more about this subject than if I had just read an article or a book. (Jacobson, Militello, and Baveye 2009, 578)

It should, however, be noted that the report contains very few details concerning how data illustrating students' actions (e.g. returning to the VFT to look-up information or accepting different opinions during class discussions) were collected and analysed.



*The virtual museum*

Possibilities to observe marine organisms for educational purposes are generally limited to marine museums that are often located far from schools. This fact motivated Tarng and his colleagues (2008) to create a virtual marine museum for elementary education in Taiwan. The goal of this virtual museum is to help students realise the importance of marine ecology and to establish the concept of environmental protection when working in their own classroom.

The virtual museum is divided into four different sections:

- A transparent tunnel displaying large marine specimens such as shark, tuna.
- A freshwater area displaying freshwater fish species from different Taiwanese ecosystems such as creeks and dams.
- A seawater area displaying seawater fish species from different ecosystems such as tidal zones and coral reefs.
- A breeding area where visitors receive a virtual aquarium to breed their own fish and a budget to buy animals and food.

Tarng and his colleagues (2008) tested the virtual museum on three computer-skilled teachers and six students from the fifth and sixth grades. This qualitative study was based on in-depth interviews with teachers and students as well as on observations of activities.

The results of the study show that the students were interested in the virtual museum and considered it more interesting than a textbook. The authors also briefly mention that the students found it enjoyable to take part in the activity, arguing that 'students were mostly focused on the contents of the virtual marine museum because they had never seen such kind of Websites' (Ibid., 56). This raises questions as to whether the fact that students 'had never seen such kind of Websites' per se implies that they focused on the content rather than on the entertainment element. Thus, the game-based learning greatly increased students' interest and learning motivation but there were no quantitative results regarding students' learning outcomes. This delicate trade-off is discussed further in relation to the E-Junior activity in the following section.

While teachers seem to find that this kind of activity has many advantages (e.g. motivating learners, avoiding problems associated with field trips), it is important to notice that the activity also involves challenges. In this study, for example, the teachers encountered problems due to certain plug-in requirements that were not available on the school computers, and they thought students might lose patience if they had to overcome the downloading issue by themselves.

### *E-Junior*

Even schools situated by the sea can encounter difficulties when it comes to gaining access to the marine environment, since most of it is hidden under water. The E-Junior application, based at the aquarium "L'Oceanogràfic" in Valencia (Spain), was tested for the teaching of sixth graders about ecology and natural science. E-Junior is designed to be a serious virtual game (including a combination of curricula content and computer games) introducing an ecosystem endemic to the Mediterranean Sea: beds of the seagrass *Posidonia oceanica*. After an introduction presented by a virtual narrator (a fish), students participate in the photosynthesis of the beds and judge the effects of humans on different animal and vegetal species. Each student uses polarised glasses to view the virtual environment, and paddles with augmented reality (AR) technology to navigate through the world.

Forty-eight students aged 10–11 years took part in the study, lead by Wrzesien and Alcañiz Raya (2010), with the students randomly assigned to either the virtual group or a traditional one. Both groups visited the aquarium L'Oceanogràfic in order to avoid the effects of only one experiencing a new and exciting place. The traditional group attended an interactive presentation given by a teacher, but without the use of any educational material or media, while the virtual group interacted with E-Junior and learned about the exact same ecological information from the virtual fish narrator. Activity evaluation was conducted via pre- and post-tests on natural science and ecology topics, combined with observations of the students in the virtual and the traditional groups. While both groups presented a significant increase in knowledge in the post-test, there was no significant difference between the results of the post-tests of the two groups.

While observing the students from the E-Junior group, the authors reported deep engagement, involvement, immersion and good collaboration between players. But the level of attention when the virtual narrator was speaking was not very high. As a matter of fact, students were more inclined to run around trying to interact with the software than pay attention to the narrator's instructions. The observation that the entertainment element seemed to temporarily overshadow the educational is supported by the students' comments regarding the virtual narrator, whom they thought spoke too much: '(I would change) that he (the virtual tutor) stops talking so much and give us more time to play' (Ibid., 184).

It is interesting to note that while the majority of comments made by the students in the virtual group mentioned the latter's satisfaction concerning the activity's game dimension – particularly its aesthetics – rather than its learning dimension, those in the traditional group expressed happiness about what they had learnt of the sea.

### *The VEP*

The use of an ecological pond to teach natural and environmental science is common practice in Taiwan. However, the construction and maintenance of such ponds requires considerable manpower and other resources. In this respect, a VEP can be a convenient alternative.

The VEP created by Tarng and co-authors in 2010 is based on the "Aquatic life" national learning unit of the Taiwanese elementary school natural science curriculum. The VEP was designed with the aim of students meeting some of the learning goals of the "Aquatic life" unit, such as knowledge of different aquatic environments, being able to identify aquatic plants, recognise the characteristics of aquatic animals and, finally, learning how to care for ecological ponds. The virtual décor represents a school campus containing two ecological ponds, with detailed information regarding many types of organisms displayed. Users can also observe the consequences of diverse modifications to the ecosystem, such as what would happen if dominant or foreign species were removed. This feature helps students understand the impact of an invasive species or the loss of key species from the pond.

In order to evaluate the learning efficiency of the VEP, Tarng and co-authors (2010) randomly selected two classes in grade three. One class used computers to work with the VEP, while the other was subject to a more traditional teaching method involving videos and PowerPoint presentations. The students completed pre- and post-tests aimed at evaluating their memorisation, comprehension and critical thinking in relation to aquatic life. While both groups significantly improved their performance between the pre- and post-tests, their memorisation and comprehension were seemingly unaffected by variation in teaching method. In contrast, the results for critical thinking were (albeit only just) significant, suggesting that the VEP might increase this ability. However, what in the study is referred to as a 'traditional method' (Ibid., 396) also involves the use of digital media; it would therefore have been useful to compare the presented results with those of a group visiting a real ecological pond.

A vast majority (92%) of the students answered that the VEP was an interesting and efficient way to present aquatic life, with a surprising 87% also feeling that the VEP was more interesting and convenient than a real pond. This last observation is noteworthy for a subject such as EE that is heavily linked to the direct experience of natural phenomena in the field.

Tarngand and his colleagues (2010) conducted in-depth interviews and made observations in order to complement the quantitative results. The interviews revealed that the students were excited by the ability to dive into the water and swim around in the pond, while they also considered the VEP to be more interesting than the method using PowerPoint presentations and videos.

### *Video podcasts*

Hill and Nelson (2011) investigated how sophomore university students from Bristol, attending a course on biogeography and conservation, perceived the learning utility of video podcasts on exotic ecosystems. The course itself aimed to improve student understanding of ecosystem structure and dynamics. According to the authors, the podcasts were developed in order to 'bring the "outside" (especially exotic locations) into the classroom and/or to wider learning experience' (Ibid., 394). Six video podcasts, 15–20 min in duration, each covered two topics: hot deserts and tropical rain forests. The podcasts were available on the university's virtual learning environment, with students able to watch them in the computer laboratories at the university or download them onto their own computers or mobile devices. The effectiveness of the podcasts was evaluated via written questionnaires, focus group interviews and through an examination of assessment results.

The students found that the podcasts supported the lectures and helped them to actively engage with their learning, as expressed by the following students during a focus group interview:

> Some things are quite abstract … just reading about them or hearing about them, but to see them was quite good. It puts them in the context of the environment. (Ibid., 400)

> Visually being able to look at the plants and species helped me to link together all my learning. (Ibid., 400)

Students reported that their learning was supported by the podcast. However, whether their feelings translate into better test performance is still an open to debate. The authors compared the results of two cohorts of students on the same course (one with podcasts in addition to the lectures and the other with lectures only), but found no difference in average grade between these two years.

### *The EVFL*

In 2005, Ramasundaram and colleagues created an EVFL in order to study the environmental properties and processes of the flatwood (soil series with impaired drainage formed from marine sediments) landscapes in Florida. The idea behind this EVFL was to mimic learning processes that would occur during a real field trip, by virtually:

- Walking through the environmental system to explore and experience a variety of environmental factors (e.g. soil, terrain, land use).
- Exploring and learning about a defined geographic domain (and subsequently transfer the knowledge to other unvisited ecosystems).
- Reproducing the scientific investigation method (observation, developing a hypothesis, testing it, refining/modifying it), leading to a better understanding of how scientific research is conducted.
- Exploring the relationship between environmental factors and different spatial and temporal scales.

The EVFL includes different types of media and interactions such as animations, 3D models, focus questions, hyperlinks and simulations. During this activity, students investigate the hydrological response of the flatwood landscape to different forest management regimes, with the focus questions encouraging students to select a scenario (e.g. silvicultural treatments) in order to closely observe its impact on ecosystem processes and to interpret the causality.

The authors highlight that while EVFL goes beyond what a conventional field trip can provide for students, it is designed only to enhance courses and by no means serve as a substitute for direct interaction with the environment. Their report is also simply a description of the tool and of its development and does not provide evaluation data, reflections on the challenges that might be encountered by students, or any form of learning outcome evaluation.

### *The Acid Ocean virtual laboratory*

Many researchers agree that hands-on experiments are a key factor in enhancing student learning in science education (e.g. Nersessian 1989; Ma and Nickerson 2006). As much as field trips are often logistically impossible to organise as part of formal education, environmental experiments can also be challenging to run for the same reasons (time, money and security issues). Once again, ICT may provide a sustainable alternative with which to get as close as possible to running a real experiment.

A virtual laboratory developed by Fauville and colleagues (2011) which tests the effect of variation in seawater acidity on marine larvae gives high school students the opportunity to gain a deep insight into ocean acidification, one of the main environmental issues of the twenty-first century (see Doney et al. 2009 for a review). Students first navigate through an interactive lesson explaining the nature of ocean acidification and its potential impact on marine life before running an experiment investigating sea urchin larvae development. Fauville and co-authors (2011) evaluated the knowledge outcome of this virtual laboratory for Californian and Swedish high school students by giving them pre- and post-tests targeting their understanding of ocean acidification, with the results demonstrating a significant increase in knowledge after running the virtual laboratory.

In order to study the students' ability to transfer knowledge to a new environmental problem, a large-scale evaluation was conducted in California. This study included 4 teachers and more than 500 students aged between 12 and 18, all using the virtual laboratory. Students answered a pre- and post-questionnaire, including a problem-solving task in which they were asked to formulate exactly what characterises an experiment and to elaborate on how an experiment may be designed in order to provide information relevant to a problem. Out of almost 500 students who answered both the pre- and post-questionnaires, a sample of 80 students was randomly selected for data analysis. The answers of this group were then classified according to the quality of their content. Between the pre- and the post-test, 43% of the students presented a progression towards a higher category, showing that they had increased their knowledge of how to organise an experiment and what it means to gain knowledge from experimentation (Petersson, Lantz-Andersson and Säljö 2011). The study also revealed that the students had begun to appropriate the terminology relevant to the organisation and discussion of experiments (terms such as *pH, test, measure* and *sample* were used most frequently in the post-test).

### *River City*

Some tools offer the opportunity to recreate the problem-solving process carried out by scientists during an environmental investigation. River City and Quest Atlantis (QA) are examples of educational multi-user virtual environment games, situating experimentation in a context in which a real scientist might operate. In River City, middle school students address issues from the nineteenth century using their twenty-first century skills and technology. Based on authentic historical, sociological and geographical conditions, River City is a town with health problems. Students work together in small research teams to help residents understand why they are becoming ill, using technology to not only keep track of clues that hint at causes of illnesses, but also to form hypotheses, develop controlled experiments with which to test their hypotheses and make recommendations based on the data they collect; all of this is carried out in an online environment. While River City is targeted at science education rather than EE, its multidimensionality and the highly environmentally oriented issues that are addressed in the game make it an interesting tool for EE as well.

While entering River City, the student's avatar interacts with the computer-based residents of the city, with objects and with the avatars of fellow students. During their exploration, students encounter visual stimuli such as muddy streets and auditory stimuli such as people coughing, both of which provide clues as to the situation in the city. The students' avatars are also equipped with interactive tools such as a water-sampling tool, mosquito net, lice tester, stool tester and so on. The students can also choose to sample water from the river at different stations. While clicking on the station, a microscope slide appears showing the microbes which can then be counted. A unique feature of this educational game is the possibility for students to modify a single parameter in identical contexts in order to determine the impact of this particular parameter on the disease and to test their hypothesis (Ketelhut and Nelson 2010).

In 2010, Ketelhut and Nelson investigated the learning outcomes of River City for 500 seventh-grade students. Five science teachers were also selected as they were considered to engage in lessons involving effective scientific inquiry on a weekly basis (according to their supervisors or the teachers themselves). Two treatment groups (whole classes) were randomly formed: a computer-based group using River City and a control group experiencing lesson features similar to those featuring in River City, as well as a physical experiment. Students completed several questionnaires, including a pre- and post-test examining content knowledge, a pre- and post-science affective measure test and, finally, a project evaluation questionnaire. The teachers also completed a pre- and post-questionnaire examining different aspects of the implementation of River City in their classrooms.

Whereas both groups improved equally between the pre- and post-test, the performance of the bottom half of the students using River City improved by 11%, while that of the bottom half of those experiencing traditional teaching increased by only 1%.

In scrutinising the inquiry process relating to the use of River City, Ketelhut and Nelson (2010) found an apparent positive effect of using the digital teaching tool over traditional methods ($p = 0.07$). The authors also highlight the increased engagement of students using River City compared with the group exposed to traditional teaching methods. The students using River City appreciated the digital tool because of features such as:

- Inquiry.
- Tools for experimenting.
- 'Like real life' or 'like being a scientist'.
- Better or different from science class.

Although the teachers testing River City considered its inquiry dimension to be the most effective for student learning, they also explained that it was difficult to manage this class because the groups seemed more disorganised and moved in too many directions compared with the control group.

### *Quest Atlantis*

QA supports school-based participation in social, environmental and scientific inquiry for children aged nine to sixteen (Hickey, Ingram-Goble, and Jameson

2009). QA makes use of various forms of media, such as its 3D multiuser environments, educational quests, unit plans, comic books, novels, board games, trading cards, series of social commitments and various characters. The QA community is comprised of both virtual spaces and face-to-face QA centres (e.g. elementary schools, clubs). In order to participate, children must be associated with a particular face-to-face QA centre and must register on the QA website, whereas teachers willing to join QA must follow an online professional development module training them how to efficiently integrate QA into their classroom activities.

QA includes four virtual worlds (unity, culture, ecology and healthy), with each divided into three villages named according to their theme (e.g. animal habitat, water quality, community power) and including up to 25 educational activities known as quests. The quests take between 20 minutes and one week to complete; all are connected to specific academic standards as well as being designed to foster critical thinking and meta-cognition (Lim 2008).

QA is based on a classic game scenario: the Atlantis civilisation is facing ecological, social and cultural decay due to the pursuit of prosperity and modernisation. Users are asked to help the Council of Atlantis restore the lost wisdom by investigating and suggesting solutions to specific issues (Barab et al. 2005).

Users move in the 3D world, interacting with other players via an instant messaging system and with non-player characters (NPC) via structured dialogue, the latter changing over time as the user makes progress towards the goal. The student's final response to solve the quest is submitted to a particular NPC inhabited by the teacher.

Some QA quests focus on EE, such as that which asks users to investigate the decrease in a fish population along a river. During this activity, students interview NPCs and collect water samples to form hypotheses about possible causes of the problem, before then being asked to write recommendations aimed at improving the situation. In the final scene, the user is able to see the consequences of his/her recommendations (Hickey, Ingram-Goble, and Jameson 2009).

In 2008, Lim studied the impact of QA on the learning of English, Mathematics and Science in two primary school classrooms with about 80 students. The evaluation was carried out via:

- Field observation.
- Pre- and post-commitment testing.
- Pre- and post-academic motivation questionnaires.
- Interviews with teachers and students.

Lim was also interested in different aspects linked to motivation, such as how threatening the students consider the classroom environment to be and how they may engage in behaviours that imply that they do not ask questions and/or fail to engage actively in learning. According to Lim the 'classroom threatening' feeling is related to anxiety and the avoidance of asking for help. In order to measure this dimension, students were asked whether they agreed or disagreed with statements such as 'I do not participate in class because I do not want to look stupid'. Lim discovered a significant decrease in this perception of the classroom setting as threatening when students were using QA, stating that this decrease 'might be attributed to the positive and non-threatening learning environment created by the author and teachers, mediated by QA' (Lim 2008, 1084–1085).

The same author also found a significant increase in intrinsic and extrinsic motivation, with a key component of the former seeming to be the fact that the programme's context was perceived as meaningful. After being immersed in the story of QA, students reported feeling committed to the mission.

Hickey, Ingram-Goble, and Jameson (2009) also evaluated the outcomes of QA use in comparison to those associated with traditional learning, employing multiple-choice tests to do so. The student subjects demonstrated an ability to use their gained knowledge in other contexts (distal-level learning). While they significantly increased their scores in both learning contexts, the students using QA improved slightly more than those taught via a traditional technique– although, as the authors point out, this might have occurred by chance. The situation was similar when the authors examined proximal-level learning. While the average gain of those experiencing the digital treatment was twice as large as those in the traditional learning treatment, the statistical analysis again suggested that this discrepancy may have occurred by chance. However, such a repetition of 'slightly increased scores' in terms of both distal- and proximal-level learning decreases the likelihood that the observed borderline effects were due to random fluctuation.

Significantly, the results obtained by the two teams concerning the quality of the problem-solving are contradictory. Lim (2008) reported that teachers working with QA thought that the content and analyses associated with the submitted quests were more in-depth than those of "normal" homework. A year later, Hickey, Ingram-Goble, and Jameson (2009) assessed the same type of problem-solving assignment using the same QA activity. During the first iteration, the quality of the quests submitted was very low (on average 3.7 out of 14 possible points), with no significant improvement observed even after resubmission. After refining the activity (including a modification of the 3-D environment and the lesson plan; for details see Hickey, Ingram-Goble, and Jameson 2009), although the quality of the students' first submission was again very low (with an average of 3.0 out of 14), it significantly increased after the second submission (average 6.0 out of 14). It is interesting to observe that these two studies, evaluating the learning outcome of the same activity, produced different conclusions. However, it must of course be taken into account that while the digital tool employed was the same, the pedagogical contexts were different, which makes such tool evaluations challenging. We will return to this discussion later.

### *Under Control*

Many researchers agree that collaborative activities have the potential to foster learning (e.g. Slavin 1996; Webb et al. 2008; Rozenszayn and Ben-zvi Assaraf 2009) by giving students the chance to share their thoughts, clarify their thinking and consolidate their ideas (Hmelo-Silver, Nagarajan, and Day 2002). The use of ICT is said to offer new tools with which to better structure and facilitate such collaboration and knowledge building, offering in particular the opportunity for people to collaborate across boundaries. In line with these assumptions, a sub-field of the learning sciences known as computer-supported collaborative learning (CSCL) emerged in the 1990s and is now a rapidly evolving field that is undergoing continuous change. CSCL studies combine the ideas associated with collaborative learning in small groups with technology support, as exemplified by the Under Control project.

Eleven middle school classrooms participated in the Under Control project, investigating the long-term impact (environmental, economic and cultural) of dam construction on the Missouri River in the mid-1900s. Students were asked to search for and analyse different points of view regarding the Missouri River's dams and to produce a policy statement for river management. The wiki environment was chosen as a collaborative content creation tool. A number of school teams were formed in order to investigate the issue under different perspectives (e.g. river flow, tribal water rights), with each team divided into research groups comprised of four to six students, each owning their own wiki page. The project lasted for about four months from initial teacher training to completion.

The teachers involved reported two main challenges when joining the project. Firstly, the computer laboratory model widely used in school was not especially compatible with the wiki page component, since wikis do not allow multiple users to log in and edit at the same time. As a result, some students were locked out of the wiki when other students were editing. A number of teachers tackled this issue by assigning a specific role within the group to each student, thus avoiding overlapping tasks. The second problem encountered was associated with access to the school computer laboratory. One teacher reported being able to use the laboratory for only two hours during the entire project period due to high demand for the room (Engstrom and Jewett 2005). Moreover, some teachers admitted having difficulty using wikis, despite completing a workshop in order to familiarise themselves with different features of the project. Finally, teachers were concerned about the lack of active communication between teams on the wiki, with students seeming to simply post messages rather than exchange ideas and give substantive feedback. Even though the authors do not provide a record of any proper learning evaluation, the reports of the challenges encountered represent valuable results that new projects can learn from.

### *Appropedia*

Service learning is a teaching and learning strategy that integrates community service with instruction and reflection in order to enrich the learning experience, teach civic responsibility and strengthen communities. It is also an important component of universities in the USA that are becoming increasingly keen to offer service learning programmes addressing sustainable development across the globe. Although the expense of sending many students abroad has been a major limitation to such programmes, once again ICT offers an attractive alternative.

Appropedia.org is a wiki website promoting collaborative approaches to sustainability, poverty reduction and international development. The website was employed in 2007 as part of the distance course 'Physics of energy and the environment' at the Clarion University of Pennsylvania, with the course directors aiming – among other things – to increase students' understanding of the link between decisions relating to human energy use and environmental issues. Appropedia was then used to coordinate a service learning outreach campaign on energy sustainability, focusing on retrofitting incandescent traffic lights with Light-Emitting Diode (LED) lights (much more efficient) in order to help local communities with their sustainability efforts. Each student involved selected a municipality, carrying out a traffic-light audit of all intersections and calculating the potential saving in terms of both costs and environmental results achieved by upgrading to LED lights. Having shared a document help to make each other's campaigns a success, the students wrote to local stakeholders and set up an appointment at which they could present the potential savings that could be made from an LED retrofit. This project demonstrates how, without moving outside of their local areas, students were able to contribute to sustainable development in their region and provide significant information on sustainability which could then be used all over the world (Pearce 2009). While omitting any real evaluation, Pearce does mention a potential obstacle, which may arise when working with wikis, arguing that honest discussion between students might be inhibited when discussing a difficult topic since everyone can read what each other wrote. However, the author provides no indication as to whether this particular obstacle was experienced or described by the teachers and/or students participating in the project in question.

### *Outdoor learning activities*

When used during field trips, portable computers have several unique features facilitating innovative exploratory learning activities (Klopfer, Squire, and Jenkins 2002):

- *Portability*: computers can be taken from one location to another with the user.
- *Social interactivity*: data can be exchanged between people face-to-face.
- *Context sensitivity*: different real and virtual data can be collected depending on the environment, location and time.
- *Connectivity*: computers can be connected to each other or to a network where data collected can be gathered together and shared.
- *Individuality*: computers can provide unique scaffolding that is customised depending on the user's path of investigation.

When focusing on EE, two main potential advantages appear in the literature: the ability to generate scientific data, and the ability to simulate an environmental investigation in the field.

#### *Sense project*

The importance of engaging students in real scientific activities has been widely discussed (Peacock 2006; Rocard et al. 2007), along with the difficulty of doing so within the school academic structure (Woodgate and Fraser 2005). Some authors believe that e-Science can serve as an opportunity to engage both students and teachers in authentic scientific inquiry in collaboration with professional scientists (Fraser et al. 2005; Underwood et al. 2008; Smith et al. 2009). In their review of e-Science in education, Woodgate and Fraser (2005, 15) define e-Science as 'the use of ICT in education, to enable local and remote communication and collaboration on scientific topics and with scientific data'.

The SENSE project (Fraser et al. 2005) made use of sensor technology in order to engage students in the collection and analysis of authentic air pollution data. The project involved one class of students aged 10–11 years, and another class in which the students were 13–14 years of age. In groups of three or four, the students were asked to capture, manipulate and reflect on their own carbon monoxide (CO) data, collected in the field. The students were provided with a local map to plan their measurement location, a CO sensor, an anemometer and a video camera in order to contextualise their data. Upon returning to the classroom, the students reviewed their data and reflected on the hypothesis formulated prior to data collection. The main challenge encountered during this project was that the students occasionally doubted the technology of the sensor. For instance, when measuring exhaust fumes from a lorry and finding that the CO concentration did not change, one group reacted with 'that is rubbish!' When another measurement taken by the sensor was lower than the students had expected, they seemed to question both the equipment and their experimental reasoning. It is interesting to note that although the description of the students' behaviour implies some kind of observation made by the researchers, the precise conditions of this evaluation are not specified. Thus, the study does not include students' learning outcome. Indeed, it is not stated whether all the analyses were based on field observation, or completed with interviews, video recordings or any other type of data collection method.

*Environmental detectives*

AR, as defined in the 2011 Horizon Report (Johnson et al. 2011, 5), 'refers to the layering of information over a view or representation of the normal world, offering users the ability to access place-based information in ways that are compellingly intuitive'. The use of AR in handheld computing has the potential not only to immerse students in the role of scientists conducting investigations, but also help them to understand science as a social practice in which investigation is a process of combining multiple data sources, forming and revising hypotheses *in situ* (Squire and Klopfer 2007). Such use of AR seems particularly relevant for EE; studying the impact of a pollutant spreading, for instance, might be educationally valuable but is of course inadvisable to reproduce in reality simply for the sake of education.

Environmental detectives (ED) is one of the most widely documented AR software programs currently employed in EE (Klopfer, Squire, and Jenkins 2002; Squire and Klopfer 2007; Klopfer and Squire 2008). The goal of the game is to give students an experience of leading a complex environmental science investigation with social, geographical and temporal constraints. ED participants work in teams of two or three, playing the role of environmental engineers investigating a chemical spill in a watershed. Moving in the real world, the handheld computer provides a simulation whereby students can take virtual samples, interview virtual people and obtain local geographical information. The handheld computer is equipped with a Global Positioning System and thus when the students sample chemical concentrations, the data are consistent with the location (i.e. a sample close to the virtual source of the spill will have a much higher concentration than would a sample further away). ED includes a multimedia database containing multidisciplinary information regarding the pollutant, such as its nature, the health risks involved, the history of the spill, Environmental Protection Agency regulations. Students also have the opportunity to interview virtual experts from different fields relating to the spill. AR simulation thus allows students to test different inquiry strategies in a safe place, where failure is possible and also beneficial for educational purposes.

The first round of trials included three higher education classes (two scientific writing classes and a teacher education class focussing on ICT for teaching). Each group was followed by a minimum of two researchers who observed participant interaction, took field notes and videotaped the activities. Most student groups were able to complete the activity in about two hours. The groups focused on data collection via drilling and although they succeeded in locating the spill and showed enthusiasm, they failed to construct a valid action plan. Another round of testing was carried out using a high school environmental science class. Due to the younger age of the users, the language was adapted and additional background information provided. This time the students were asked to engage in a kind of scavenger hunt, trying to collect as many interviews as possible in the hope that one would provide the correct solution to the environmental issue. However, by the end of the day, most of the groups had insufficient data with which to locate the source of the chemical spill (Klopfer and Squire 2008).

The authors argue that the virtual spread of the toxin through the students' community was a much stronger motivator than when the game was played in an unfamiliar area. Only a few groups managed to reach a valid solution which included both the gathering of data regarding the origin of the toxin and regarding previous accidents (collected in the library), and the successful creation of a remediation plan. The students did not really manage to formulate valid solutions by taking into account the drawbacks and strengths of their plans, instead opting for politically correct solutions such as tree planting. Finally, Klopfer and Squire (2008) emphasised that the ability to learn from ones mistakes in ED was an important factor in the pedagogical success of the activity; students were shown the benefit of playing multiple run-throughs and that it is possible to learn from previous mistakes and test new strategies. While this sounds promising, it is important to highlight that none of the teachers using ED in this article had enough teaching time available to perform multiple iterations of the game.

### *TimeLab 2100*

The scenario of the TimeLab 2100 project is set during the early twenty-second century; climate change is now out of control, and players are instructed to alter the past by placing new items on the local election ballot. TimeLab 2100 was tested by an unspecified number of university students. The players were paired, with each group asked to investigate different ballot measures related to climate change. The students were equipped with a handheld device (displaying information regarding the scientific implications of each ballot option) and explored different areas of the Massachusetts Institute of Technology campus, encountering scenarios related to their position. The students were also required to share information received by their own virtual guides in order to have a global vision of the impact of each ballot item. At the end of the activity, the groups gathered to debate the three measures to be put on the city ballot (Klopfer and Sheldon 2010). The authors of the report observed that users were able to connect the virtual future with their own personal experiences.

TimeLab 2100 takes both the importance of the trade-off between portability (the ability to move the game from one place to another) and location specificity (having the game connected to the real landscape) into account. Of course, games that are not location-specific can be easily used in any backyard at no cost, but will undeniably lose the meaning associated with familiar real-world locations (as experienced in ED, described above). In order to offer a solution to this trade-off, a drag-and-drop interface was designed, allowing teachers to design their own version based on their teaching location. After various attempts, it became clear that the best way to proceed was to let students create their own game, thus becoming creators in their own right (as described above regarding The Orchard). Klopfer and Sheldon (2010) argue that this shift from player to creator gives students the opportunity to engage in important cognitive tasks and develop technical skills, along with the opportunity to be creative. The games created by the students were considered to illustrate their personal understanding of the topic and thus serve as a suitable tool with which to communicate with the community at large. Results achieved using a new program based on the game builder and preliminary feedback from teachers and students indicate that it supports student involvement in issues facing their own communities.

### *Using mobile phones to increase local environmental awareness*

In western countries, most students own a mobile phone, often using them for a variety of purposes. Although small and unobtrusive, such technology might be an efficient tool with which to increase students' environmental awareness with respect to their own local neighbourhoods.

In 2009, Uzunboylu, Cavus and Ercag carried out a six-week programme involving 41 university students, aged 19–24 years (sophomores, juniors and seniors) and enrolled in computing classes in Cyprus. During the first meeting, in which the researchers presented the study to the volunteers, they noticed that the students did not rate environmental issues as a high priority in their lives. The authors then asked the students to complete a pre- and post-test concerning the usefulness of mobile telephones in order to increase their awareness of environmental issues.

During the programme, the subjects used their mobile phones to take snapshots of local topics such as environmental blight and social events; these pictures were sent to the moderator via MMS each week. All participants had access to a website on which all pictures could be reviewed and comments posted via SMS. The students were also instructed to download Windows Live Messenger in order to enact a weekly discussion of the posts and to suggest solutions as to how to overcome the environmental problems.

A comparison of pre- and post-test results indicated that not only had student awareness of environmental blight increased, but that they also possessed a better appreciation of the benefits of using mobile technologies to address environmental problems.

## Discussion

The above literature review covers several types of digital device (handhelds, computers, mobile phones) used in settings ranging from primary to university education, from outdoor trips to indoor adventures. The purpose of the review is not to provide a complete breakdown of ICT in EE, but rather to give an overall view of the affordances and constraints associated with ICT tools that are currently available for use in EE. Indeed, one key finding is that there is a rich variety of such tools and applications. However, there has been far less research carried out examining how such tools are used and what that implies for student learning. In fact, there seems to be a much greater interest in designing such tools than in analysing how their use contributes to shaping student learning and understanding of environmental issues (an observation also made in other areas of education: cf. Arnseth and Ludvigsen 2006; Jahreie et al. 2011).

The studies described in this paper are seen as potential EE learning activities as they fulfil at least four of the six criteria listed by the UNESCO (1975, 1977). These criteria are awareness, attitude, skills, participation, and interdisciplinary as well as local and international dimensions. As shown in Table 1, all the studies possess three of the criteria. They all seem to have the potential to raise awareness and sensitivity to the global environment, to help acquire attitude (values and feeling) of concern for the environment and to understand the significance of attending to such issues with a multidisciplinary approach. Most of the activities seem to evoke skills for identifying and solving environmental problems. A difficult criterion to fulfil seems to be the international and local dimensions that nevertheless seem essential to be able to develop a holistic view of the issue as stake as well as a concrete and local understanding. Finally, only few activities seem to have the potential to actively involve the students in working towards resolution of environmental problems. This is an important finding since the ability to take concrete action to tackle environmental issue might be seen as the ultimate objectives of EE.

The present review provides a birds-eye view of ICT in the EE landscape. The general impression of the outcomes produced after using ICT in EE is one of either a lack of significant effects on student learning and/or attitudes, or, alternatively, a slightly positive result in terms of certain outcome measures. Researchers have addressed a wide range of questions (e.g. impact on motivation and basic knowledge, comparison between ICT outcomes and traditional learning outcomes) using different methods (observation, pre- and post-tests, interviews, knowledge questionnaires), in order to test the impact of diverse technologies in different situations (traditional learning, ICT learning, mix of both) and contexts (indoor, outdoor). This diversity, combined with the rather unclear results, makes the drawing of any valid general conclusions problematic.

The difficulty of reaching a consensus regarding the learning outcomes of digital tool use is typified by the problems associated with finding one for even a single tool, as shown in the case of QA for which two different studies produced conflicting results (Lim 2008; Hickey, Ingram-Goble, and Jameson 2009). The example of QA highlights the fact that many contextual issues remain hidden behind digital tool evaluation. This testifies to the claim that it is not only the tools or the method per se which are decisive in instruction, but also how the learning activity is designed and maintained as an activity. Instructional activities are never simply determined by the technologies adopted.

Moreover, since learning takes time, the lack of clear findings is not surprising as most studies have focused on short-term projects. One consequence of this is that there is currently very little knowledge available regarding how systematic use of ICT tools over time may contribute to learning and attitude change in the area of EE. It is also important to remember that the tool to be tested is often implemented in the teacher's curriculum only for the sake of the evaluation itself. The present field of knowledge on the subject consists largely of research examining arranged situations, experimental environments and short-term interventions. Extra resources such as researchers, experienced research staff and recent digital applications also form part of such studies. When these extra resources are withdrawn, a different picture of the activity often emerges, which makes it hard to tell what the research says about regular teaching and learning. This is also most likely why the results of such studies are often hard to replicate (e.g. Schrum et al. 2005; Arnseth and Ludvigsen 2006). There exists a clear need for research that focuses on tools that are mature and that can be used in regular education, so that teachers can embed them in instruction planned on the basis of curricular considerations.

Several research questions asked by the surveyed studies focused on comparing a teaching approach incorporating the use of digital tools with a more traditional method, with the aim of revealing which of the two would provide the best learning outcomes. In line with our basic assumption that learning is contextually situated, we argue that such questions cannot be answered in a straightforward manner. Firstly, it is important to discuss whether ICT tools should be seen as competitors to traditional tools or if they should be regarded as complementary, that is, should traditional and tech-savvy education methods be seen as excluding or supplementing each other? In most cases, it would seem reasonable to argue that complementarity is the way forward. Secondly, in performing comparative research, it is important to discuss exactly what a "traditional method" implies, since this can vary considerably depending on the learning situation; for instance, it could indicate learning by means of textbooks, through discussion with a teacher and/or classmates, or running a traditional experiment. It is therefore essential to be aware of what the digital tools in question are to be compared with. If, as occurs in many studies, the tools focus on a specific issue or problem whereas it is unclear whether the traditional teaching method under study does so, the comparison would provide little of use regarding learning situations.

This literature review suggests that ICT could open up a new arena of learning experience for EE; such technologies make it possible to overcome budget, time and security issues by giving students the ability to virtually visit remote places, or virtually conduct experiments that are not possible to physically run at school. Ultimately, it is essential to realise that environmental issues often involve very complex systems. For example, increased greenhouse gas concentrations are responsible for a variety of different environmental issues including global warming, ocean acidification and marine hypoxia. Although these three issues primarily interact with each other by combining their negative effects on species and habitats, they are also associated with additional environmental issues not directly related to greenhouse gases, such as overfishing and deforestation. Moreover, the impact of human behaviour on greenhouse gas emissions reflects a melange of cultural, social and economic factors that cannot be considered independently. As Sheehy and colleagues (2000) argue, combining the ability to identify the causes of these issues with the ability to find a solution requires a good understanding of these complex relationships, or at least an awareness that such complex systems exist. Unfortunately, many scholars have highlighted the general lack of conceptual understanding regarding climate change and the prevalence of misconceptions (Boyes, Chuckran, and Stanisstreet 1993; Fisher 1998; Pruneau et al. 2001). ICT might offer new ways to help students visualise and get a grasp on this type of complex system, thanks to its ability to merge different disciplines and run over different temporal and spatial scales. ICT thus has the potential to provide a visualisation of the dynamics existing between the different parameters involved in any environmental issue.

However, the implementation of ICT in schools also comes fraught with many challenges that are interconnected with EE. For teachers the most common hurdle seems to be associated with anxiety, either that they may lose their professional credibility in front of their students, who might be more knowledgeable about ICT (Guha 2003), or that they will make mistakes so that the activity does not work as intended. In some cases, it has even been reported that teachers may be afraid of damaging the technology through their own lack of competence (Bradley and Russell 1997). This latter type of anxiety could be linked to insufficient professional education of teachers regarding technology and computer skills (Pelgrum 2001). Although such issues may decrease as average ICT competence increases, it is nevertheless desirable that teachers, along with hands-on support, are also given the opportunity to develop theoretically grounded understanding and attitudes in relation to ICT, in order to be able to pedagogically implement and use such tools. In 1996, Wild advocated that before knowing how to use a computer for instructional purposes, teachers should consider how ICT tools may be integrated with educational activities. The author also marked that this represents a significant challenge for the educational system.

Computer software and hardware can also bring additional challenges for educators wanting to implement digital technology in their teaching. Both a lack of accessibility due to an insufficient number of computers, and a lack of Internet access or suitable software, still seem to be important issues facing some school systems (Pelgrum 2001; Toprakci 2006). Similar problems were also encountered by Engstrom and Jewett (2005) during the Under Control project described earlier in this review, with the lack of technical support resulting in teachers wasting time trying to fix ICT problems that they were often not trained to deal with. Such challenges were also observed by Tarng and co-authors (2008) with respect to the virtual museum project, in which teachers needed to download a certain plug-in in order to use the software. Of course, the occurrence of bugs will also negatively impact the rate of teacher readiness to implement ICT (Cuban, Kirkpatrick, and Peck 2001). Finally, Newhouse (2002) asserts that another obstacle is the use of digital tools that are not school-adapted; such tools may erode teachers' motivation to spend time trying to implement ICT to improve their teaching.

A result common to the various research projects summarised above is the fact that students largely appreciate being able to engage with digital devices as part of learning. While this is certainly an important observation, the entertainment aspect of certain software programs may also obstruct students from focusing on and reaching the learning goals entailed in an activity. In terms of their output in relation to ICT tools, the present overview also indicates that students' work at times tends to be rather mechanical, being more focused on clicking with the computer mouse and working their way through the software, rather than carrying out the experimentation or exploring the content at hand. Lantz-Andersson, Linderoth, and Säljö (2009) investigated this phenomenon with software used in mathematics teaching. When students entered an incorrect answer and received a message that their answer was false, they left the mathematical discussion and instead attempted to solve the problem by focusing on the functionality of the software; understanding mathematics seemed to play little or no role in their deliberations for long periods of time. This implies that many of their actions and interactions were devoted to speculation regarding the syntax features of the digital tool and to testing whether there was something wrong with the answer function. Several authors (Tarng et al. 2008; Wrzesien and Alcañiz Raya 2010) cited in the present review have discussed similar types of dilemma concerning the shift in focus from content to technology logic. In instructional settings, the user is often not familiar enough with the activity that they engage in, and do not always have the necessary background to comprehend the object of learning (e.g. mathematics, environmental science, grammar). Therefore, the establishment of intellectual scaffolding by teachers is essential in supporting a dual focus, with the particular affordances of the mediation provided by digital tools complemented by an effort to clarify the conceptual issues in play. Digital technology thus has a dual function in the sense that while it makes some issues visible, others remain hidden to the learner.

However, as has been demonstrated by various researchers (cf., for instance, Cekaite 2011; Musk 2011), digital technologies may also trigger reflections and insights that are not so easily produced without such resources. In the context of language learning, Cekaite (2011) and Musk (2011) have shown how certain features of digital tools (e.g. spell and grammar checks) can trigger discussion among students in which important grammatical and other linguistic features are attended to in a manner that would not be possible if one had not received such on-line reactions from built-in digital resources. This phenomenon is illustrated in the present review, with an investigation of pollutant spreading being made possible through the use of AR simulation on handheld computers.

Although it is important to point to the challenges facing school systems when implementing ICT in education in general and in EE in particular, it is equally necessary to reflect on the possibility that ICT may be a potential challenge to the meeting of EE goals. Given that EE should, as far as possible, be about experiencing nature under real conditions, one potential problem with the use of ICT in EE is perfectly illustrated in a discussion between two teachers reported by Rohwedder and Alm (1995):

> Chris: Hey Robin, when should we plan to take our students on our annual field trip to the wetlands? We've got to schedule the car pools, gather up a bunch of binoculars and water test kits, and oh yeah, are you still willing to borrow your neighbor's canoe?
>
> Robin: Gee Chris, I'm really not into a wetlands field trip anymore. Not since our school got that great new interactive laserdisc on wetlands. It shows a lot more birds than we ever saw. It even plays bird calls and shows those weird bottom-dwelling insects we could never seem to find! And, hey, no more muddy boots or wet clothes. I hear there is a new tide pool CD-ROM being developed too. I'm hoping I can use it as a substitute for our annual beach trip. (Ibid., 5)

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. ICT could even be seen as contributing to one of the biggest problems for EE: an alienation from nature that many children are said to experience (Shultis 2001). This alienation hypothesis seems to be supported by students' reactions after using the VEP (Tarng et al. 2010), with most feeling that learning in the VEP was more interesting and convenient than a real pond. However, the students in question had not yet experienced a real field trip to a pond, so their opinion was based on preconception rather than experience. In a different study, Spicer and Stratford (2001) observed that although university students testing a VFT were extremely positive, they were also very insistent on the fact that the virtual should not replace the real, an opinion that was even stronger after the students experienced work in the field.

Table 3. Table presenting positive and negative attributes associated with each tool.

| | Attributes | GE | VFT | VM | E-J | VEP | VP | AOVL | RC | QA | UC | A | EVFL | SP | ED | TL | MP | Number of mentions |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Positive attributes | Trigger active or critical thinking | | X | | | X | | | | | | | | | | | | 3 |
| | Understand complexity of environmental problem | | X | | | | | | | | | | | | | | | 1 |
| | Students more interested or engaged than with traditional learning | | | X | | | | | X | | | | | | | | | 4 |
| | Students think it is fun | | | X | X | X | | | | | | | | | X | | | 4 |
| | Increase learning interest | | | X | | | | | | | | | | | | | | 1 |
| | Good collaboration, interaction between students | | X | | | | | | | | | | | | | | | 3 |
| | Help support learning, understand abstract concept | | | | | | X | | | | | | | | | | | 1 |
| | Increase environmental awareness | | | | | | | | | | | | | | | | X | 1 |
| Negative attributes | Problem due to technology requirement | | | X | | | | | | | X | | | | | | | 2 |
| | Entertainment overcomes education | | | | X | | | | | | | | | | | | | 1 |
| | Students less organized, difficult to reach initial goal | | | | | | | | X | | | | | | X | | | 2 |
| | Lack of active communication between students | | | | | | | | | | X | X | | | | | | 2 |
| | Students do not trust the technology | | | | | | | | | | | | | X | | | | 1 |

Note: GE, Google Earth; VFT, virtual field trip; VM, virtual museum; E-J, E-Junior, VEP, virtual ecological pond; VP, videopodcasts; AOVL, Acid ocean virtual lab; RC, River city; QA, Quest Atlantis; UC, Under control; A, Appropedia; EVFL, Environmental virtual field trip; SP, Sense project; ED, Environmental detectives; TL, TimeLab2100; MP, Mobile phone for local environmental awareness.

Table 3 displays a summary of how the range of reviewed ICT tools and their different learning contexts are associated with a wide variety of both positive and negative attributes.

### *A note on method*

Although the most common evaluation method comprises a combination of pre- and post-testing along with interviews, we believe that the direct observation of student interaction with digital tools provides other important information regarding the affordances and constraints associated with said tools. Student observation enables an insight to be gained into the learning activity taking place, the kinds of activity emerging in relation to the tool and how the latter serves as a mediating resource for student learning and reasoning. Moreover, such studies could provide knowledge as to how students make sense of the activity, the tool and knowledge, as well as how they relate the content of the lesson to their own experiences. Such issues will remain unanswered if the scope of evaluation excludes the learning activity. Research thus needs to contribute by both focusing on the learning activities that are occasioned by digital resources and the outcomes that are produced. Although some authors have reported the results of field observation of students carried out during the activity, video recording has rarely been used to document the implications of digital tool use. Video documentation is a suitable research method with which to analyse interaction during concrete activities between participants and various physical tools, such as the different digital tools used in the studies described here. Another advantage of the method is that it also offers the opportunity to observe the same scene several times (even in slow motion) and to share and discuss it with colleagues (Heath and Luff 2000). Along with video documentation, we maintain that in the future, recording students' interactions and discussions through online learning systems could be considered a complementary method of collecting data produced during ongoing activities.

## Conclusion

EE is a recent arrival to education systems and is yet to find its own instructional tradition. This lack of history opens the debate as to how the interests of the field can be best served within school systems that may be very much institutionalised. In addition, the multidisciplinarity of EE poses challenges for a teaching tradition that is still largely organised on the basis of individually distinct subjects.

Through the implementation of ICT in EE practice, students have access to a whole new range of experiences and fields of investigation that were not previously available. We are currently witnessing a rapid and promising blooming of ICT resources in EE, but one that will need time to grow harmoniously, while there is also an urgent need for studies that will provide models for productive teaching and learning. In the search to find modes of working that fit this socially significant curricular domain, ICT tools will certainly play an important role.

## Acknowledgements

The research reported here was funded by the University of Gothenburg Learning and Media Technology Studio (LETStudio), and the Linnaeus Centre for Research on Learning, Interaction and Mediated Communication in Contemporary Society (LinCS).

## Note

1. E.g. http://www.discoveryeducation.com/administrators/curricular-resources/science-techbook/, http://www.uwsp.edu/cnr-ap/wcee/Pages/environmentalscience.aspx, http://www.epa.gov/climatechange/kids/index.html

## Notes on contributors

G. Fauville holds a master degree in marine biology and a master degree in educational science with specialization in communication and information technologies. Géraldine is a member of the University of Gothenburg Learning and Media Technology Studio (LETStudio) and is currently coordinating three projects creating digital EE resources aimed at enhancing marine and environmental literacy among citizens.

A. Lantz-Andersson works as senior lecturer in education and holds a post doctoral at the LETStudio, a strategic initiative aimed at promoting interdisciplinary research within the Learning Sciences at the University of Gothenburg. Annika is also a member of a national centre of excellence funded by the Swedish Research Council: the Linnaeus Centre for Research on Learning, Interaction, and Mediated Communication in Contemporary Society (LinCS). Annika is currently involved in two research projects that are motivated by an interest in the role of digital media and what that implies for learning and education.

R. Säljö is professor of the psychology of education, specialising in research investigating learning and development from a sociocultural perspective. Much of his work is devoted to studying literacy, numeracy and related issues, and how the current transformation of media impacts on practices of teaching and learning. His recent publications include R. Säljö (2012). Literacy, digital literacy and epistemic practices: The co-evolution of hybrid minds and external memory systems. *Nordic Journal of Digital Literacy* and M. Nivala, R. Säljö et al. (in press). Using virtual microscopy to scaffold learning of pathology: a naturalistic experiment on the role of visual and conceptual cues. *Instructional Science*.



## References

Arnseth, H. C., and S. Ludvigsen. 2006. "Approaching Institutional Contexts: Systemic Versus Dialogical Research in CSCL." *International Journal of Computer-Supported Collaborative Learning* 1 (2): 167–185.

Barab, S., M. Thomas, T. Dodge, R. Carteaux, and H. Tuzun. 2005. "Making Learning Fun: Quest Atlantis, a Game Without Guns." *Educational Technology Research and Development* 53 (1): 86–107.

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.

Boyes, E., D. Chuckran, and M. Stanisstreet. 1993. "How do High School Students Perceive Global Climate Change: What are its Manifestations? What are its Origins? What Corrective Action can be Taken?" *Journal of Science Education and Technology* 2 (4): 541–557.

Bradley, G., and G. Russell. 1997. "Computer Experience, School Support and Computer Anxieties." *Educational Psychology* 17 (3): 267–284.

Breck, Judy. 2006. *109 Ideas for Virtual Learning: How Open Content Will Help Close the Digital Divide*. Oxford: Rowman and Littlefield Publisher.

Cekaite, Asta. 2011. "Att lära och minnas med stavningsprogram." In *Lärande och minnande som social praktik*, edited by Roger Säljö, 161–80. Stockholm: Norstedts.

Cuban, Larry. 1989. *Teachers and the Machines: The Classroom Use of Technology Since 1920*. New York, NY: Teacher College Press.

Cuban, L., H. Kirkpatrick, and C. Peck. 2001. "High Access and Low Use of Technologies in High School Classrooms: Explaining an Apparent Paradox." *American Educational Research Journal* 38 (4): 813–834.

Doney, S. C., V. J. Fabry, R. A. Feely, and J. A. Kleypas. 2009. "Ocean Acidification: The Other $CO_2$ Problem." *Annual Review of Marine Science* 1 (1): 169–192.

Engstrom, M. E., and D. Jewett. 2005. “Collaborative Learning the Wiki Way.” *TechTrends* 49 (6): 12–15.

Fauville, G., J. Hodin, S. Dupont, P. Miller, J. Haws, M. Thorndyke, and D. Epel. 2011. “Virtual Ocean Acidification Laboratory as an Efficient Educational Tool to Address Climate Change Issues.” In *The Economic, Social and Political Elements of Climate Change*, edited by Leal Filho, 825–36. Berlin: Springer.

Fisher, B. 1998. “Australian Students’ Appreciation of the Greenhouse Effect and the Ozone Hole.” *Australian Science Journal* 44 (33): 46–55.

Fraser, D. S., H. Smith, E. Tallyn, D. Kirk, S. Benford, M. Paxton, S. Price, and G. Fitzpatrick. 2005. “The SENSE Project: A Context-inclusive Approach to Studying Environmental Science Within and Across Schools.” In *Proceeding of CSCL’05,* edited by International Society of the Learning Sciences, 155–9. Taiwan: Taipei.

Guertin, L., and S. Neville. 2011. “Utilizing Google Earth to Teach Students About Global Oil Spill Disasters.” *Science Activities: Classroom Projects and Curriculum Ideas* 48 (1): 1–8.

Guha, S. 2003. “Are We All Technically Prepared? Teachers’ Perspectives on the Causes of Comfort or Discomfort in Using Computers at Elementary Grade Teaching.” *Information Technology in Childhood Education Annual* 2003 (1): 317–349.

Heath, Christian, and Paul Luff. 2000. *Technology in Action*. Cambridge: Cambridge University Press.

Hickey, D. T., A. A. Ingram-Goble, and E. M. Jameson. 2009. “Designing Assessments and Assessing Designs in Virtual Educational Environments.” *Journal of Science Education and Technology* 18 (2): 187–208.

Hill, J. L., and A. Nelson. 2011. “New Technology, New Pedagogy? Employing Video Podcasts in Learning and Teaching About Exotic Ecosystems.” *Environmental Education Research* 17 (3): 393–408.

Hmelo-Silver, C. E., A. Nagarajan, and R. S. Day. 2002. “‘It’s Harder than we Thought it Would be’: A Comparative Case Study of Expert-novice Experimentation Strategies.” *Science Education* 86 (2): 219–243.

Jacobson, A. R., R. Militello, and P. C. Baveye. 2009. “Development of Computer-assisted Virtual Field Trips to Support Multidisciplinary Learning.” *Computers & Education* 52 (3): 571–580.

Jahreie, C., H.-C. Arnseth, I. Krange, O. Smørdal, and A. Kluge. 2011. “Designing for Play-based Learning of Scientific Concepts: Digital Tools for Bridging School and Science Museum Contexts.” *Children, Youth and Environments* 21 (2): 236–255.

Johnson, L., R. Smith, H. Willis, A. Levine, and K. Haywood. 2011. *The 2011 Horizon Report*. Austin, TX: The New Media Consortium.

Ketelhut, D. J., and B. Nelson. 2010. “Designing for Real-world Scientific Inquiry in Virtual Environments.” *Educational Research* 52 (2): 151–167.

Khishfe, R., and N. G. Lederman. 2006. “Teaching Nature of Science Within a Controversial Topic: Integrated Versus Nonintegrated.” *Journal of Research in Science Teaching* 43 (4): 395–418.

Klopfer, E., and J. Sheldon. 2010. “Augmenting Your Own Reality: Student Authoring of Science-based Augmented Reality Games.” *New Directions for Youth Development* 2010 (128): 85–94.

Klopfer, E., and K. Squire. 2008. “Environmental Detectives – the Development of an Augmented Reality Platform for Environmental Simulations.” *Educational Technology Research and Development* 56 (2): 203–228.

Klopfer, E., K. Squire, and H. Jenkins. 2002. “Environmental Detectives: PDAs as a Window into a Virtual Simulated World.” Paper presented at the International Workshop on Wireless and Mobile Technologies in Education, Växjö, Sweden, August 29–30.

Lantz-Andersson, A., J. Linderoth, and R. Säljö. 2009. “What’s the Problem? Meaning Making and Learning to do Mathematical Word Problems in the Context of Digital Tools.” *Instructional Science* 37 (4): 325–343.

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.

Ma, J., and J. V. Nickerson. 2006. “Hands-on, Simulated, and Remote Laboratories: A Comparative Literature Review.” *ACM Computing Surveys* 38 (3): 1–24.
Mäkitalo, Åsa, Jakobsson Anders, and Säljö Roger. 2009. “Learning to Reason in the Context of Socioscientific Problems. Exploring the Demands on Students in ‘New’ Classroom Activities.” In *Investigating Classroom Interaction. Methodologies in Action*, edited by K. Kumpulainen, C. Hmelo-Silver, and M. Cesar, 7–25. Rotterdam: Sense Publishers.
Musk, Nigel. 2011. “Att spåra andraspråkslärande i internetstödd frågesport.” In *Lärande och minnande som social praktik*, edited by Roger Säljö, 181–206. Stockholm: Norstedts.
Nersessian, N. 1989. “Conceptual Change in Science and in Science Education.” *Synthese* 80 (1): 163–183.
Newhouse, Paul. 2002. *Literature Review: The Impact of ICT on Learning and Teaching*. Perth: Department of Education.
Palmer, Joy A. 1998. *Environmental Education in the 21st Century: Theory, Practice, Progress and Promise*. London: Routledge.
Papert, Seymour. 1980. *Mindstorms: Children, computers and powerful ideas*. Brighton: The Harvester Press.
Peacock, A. 2006. “Focus on Real Science.” *Primary Science Review* 94: 2–3.
Pearce, J. M. 2009. “Appropedia as a Tool for Service Learning in Sustainable Development.” *Journal of Education for Sustainable Development* 3 (1): 45–53.
Pelgrum, W. 2001. “Obstacles to the Integration of ICT in Education: Results from a Worldwide Educational Assessment.” *Computers & Education* 37 (2): 163–178.
Petersson, E., A. Lantz-Andersson, and R. Säljö. 2011. “Knowing Nature Through Experimentation: Science Literacy and the Situatedness of Knowing.” Paper presented at EARLI Conference 2011, Exeter, UK, August 30 – September 3.
Pruneau, D., U. Moncton, L. Liboiron, and E. Vrain. 2001. “People’s Idea about Climate Change: A Source of Inspiration for the Creation of Educational Programs.” *Canadian Journal of Environmental Education* 6 (1): 58–76.
Ramasundaram, V., S. Grunwald, A. Mangeot, N. Comerford, and C. Bliss. 2005. “Development of an Environmental Virtual Field Laboratory.” *Computers & Education* 45 (1): 21–34.
Ratcliffe, Mary, and Marcus Grace. 2003. *Science Education for Citizenship: Teaching Socioscientific Issues*. Maidenhead: Open University Press.
Rocard, M., P. Csermely, D. Jorde, D. Lenzen, H. Walberg-Henriksson, and V. Hemmo. 2007. *Science Education Now: A Renewed Pedagogy for the Future of Europe*. Luxembourg: European commission.
Rohwedder, W. J. 1999. Environmental education goes high-tech. *Human Nature: Greencom's Newsletter* 4 (1): 1–2.
Rohwedder, W. J., and A. Alm. 1995. “Using Computers in Environmental Education: Interactive Multimedia and On-line Learning.” The environmental education toolbox- EE toolbox workshop resource manual.
Rozenszayn, R., and O. Ben-Zvi Assaraf. 2009. “When Collaborative Learning Meets Nature: Collaborative Learning as a Meaningful Learning Tool in the Ecology Inquiry Based Project.” *Research in Science Education* 41 (1): 123–146.
Sadler, T., S. Barab, and B. Scott. 2007. “What do Students Gain by Engaging in Socioscientific Inquiry?” *Research in Science Education* 37 (4): 371–391.
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.
Schrum, L., A. Thompson, D. Sprague, C. Maddux, A. McAnear, L. Bell, and G. Bull. 2005. “Advancing the Field: Considering Acceptable Evidence in Educational Technology Research.” *Contemporary Issues in Technology and Teacher Education* 5 (3 and 4): 202–209.
Sfard, A. 1998. “On Two Metaphors of Learning and the Dangers of Choosing Just One.” *Educational Researcher* 27 (2): 4–13.
Sheehy, N. P., J. W. Wylie, C. McGuinness, and G. Orchard. 2000. “How Children Solve Environmental Problems: Using Computer Simulations to Investigate Systems Thinking.” *Environmental Education Research* 6 (2): 109–126.
Shultis, J. 2001. “Consuming Nature: The Uneasy Relationship Between Technology, Outdoor Recreation and Protected Areas.” *The George Wright Forum* 18 (1): 56–66.

Skolverket. 2011. *Läroplan för grundskolan, förskoleklassen och fritidshemmet*. Stockholm: Skolverket.
Slavin, R. 1996. "Research on Cooperative Learning and Achievement: What We Know, What We Need to Know." *Contemporary Educational Psychology* 21 (1): 43–69.
Smith, H., J. Underwood, G. Fitzpatrick, and R. Luckin. 2009. "Classroom e-Science: Exposing the Work to Make it Work." *Educational Technology & Society* 12: 289–308.
Spicer, J. I., and J. Stratford. 2001. "Student Perceptions of a Virtual Field Trip to Replace a Real Field Trip." *Journal of Computer Assisted Learning* 17 (4): 345–354.
Squire, K., and E. Klopfer. 2007. "Augmented Reality Simulations on Handheld Computers." *Journal of the Learning Sciences* 16 (3): 371–413.
Stevenson, R. B. 2007. "Schooling and Environmental Education: Contradictions in Purpose and Practice." *Environmental Education Research* 13 (2): 139–153.
Stokes, Eleanor, Ann Edge, and Ann West. 2001. *Environmental Education in the Educational Systems of the European Union*. London: Centre for Educational Research, London School of Economics.
Tarng, W., M. Y. Change, K. L. Ou, Y. W. Chang, and H. H. Liou. 2008. "The Development of a Virtual Marine Museum for Educational Applications." *Journal of Educational Technology Systems* 37 (1): 39–59.
Tarng, W., K. L. Ou, W. S. Tsai, Y. S. Lin, and C. K. Hsu. 2010. "An Instructional Design Using the Virtual Ecological Pond for Science Education in Elementary Schools." *Journal of Educational Technology Systems* 38 (4): 385–406.
Toprakci, E. 2006. "Obstacles at Integration of Schools into Information and Communication Technologies by Taking into Consideration the Opinions of the Teachers and Principals of Primary and Secondary Schools in Turkey." *Journal of Instructional Science and Technology* 9 (1): 1–16.
Tryse, D. 2008. "Black tides: The Worst Oil Spills in history." Google Earth. http://earth.tryse.net/oilspill.html.
United Nations of Education Scientific and Cultural Organisation (UNESCO). 1975. *The International Workshop on Environmental Education Final Report, Belgrade, Yugoslavia*. Paris: UNESCO/UNEP.
United Nations of Education Scientific and Cultural Organisation (UNESCO). 1977. *First Intergovernmental Conference on Environmental Education Final Report, Tbilisi, USSR*. Paris: UNESCO.
Underwood, J., H. Smith, R. Luckin, and G. Fitzpatrick. 2008. "E-Science in the Classroom – Towards Viability." *Computers & Education* 50 (2): 535–546.
Uzunboylu, H., N. Cavus, and E. Ercag. 2009. "Using Mobile Learning to Increase Environmental Awareness." *Computers & Education* 50 (2): 381–389.
Vygotsky, Lev. Semyonovich. 1939/1978. *Mind in society: The development of higher psychological processes*. Cambridge, MA: Harvard University Press.
Webb, N., M. Franke, M. Ing, A. Chan, T. De, D. Freund, and D. Battey. 2008. "The Role of Teacher Instructional Practices in Student Collaboration." *Contemporary Educational Psychology* 33 (3): 360–381.
Wertsch, James V. 1998. *Mind as Action*. New York, NY: Oxford University Press.
Woodgate, D., and D. S. Fraser. 2005. "eScience and Education 2005: A Review." JISC report.
Wrzesien, M., and M. Alcañiz Raya. 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.