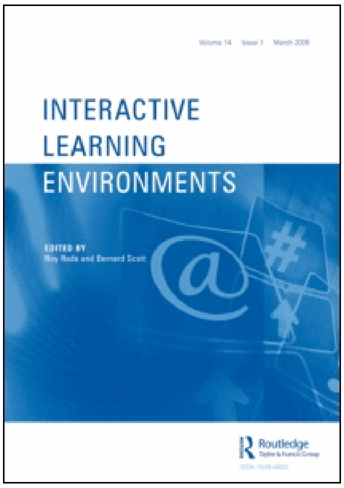

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An interactive learning environment designed to increase the possibilities for learning and communicating about radioactivity

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An interactive learning environment designed to increase the possibilities for learning and communicating about radioactivity

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Information and communication technology (ICT) is a natural part of most people's everyday life, and has also been introduced in schools. Previous studies have tended to focus on issues related to competency of teachers and lack of computer technology in schools. Focus now seems to be moving towards studies that help us understand how ICT may be used to enhance students learning. This article explores the learning environment *Radioactivity* from the Norwegian Viten project in order to provide insights into how features of the environment may influence student learning. A characteristic of the features of *Radioactivity* is provided and discussed in light of a set of quality principles for digital learning resources developed by the British Educational Communications and Technology Agency.

Keywords: interactive learning environment; animations; radioactivity; science education

Introduction

We live in a digitalised society where information and communication technology (ICT) has become almost omnipresent, and plays an increasingly significant role in both our private and working lives. ICT is also present in schools, but there have been many obstacles for successful implementation, such as lack of hardware, infrastructure, access to educational software and ICT pedagogical skills amongst teachers. It has been suggested that with the presence of ICT; complex systems can be simulated, the curriculum can be centred on 'authentic' problems parallel to those that adults face in real-world settings, modelling and visualisation can be used to bridge between experience and abstraction, and controversial topics may be discussed with experts outside the immediate classroom (Crosier, Cobb, & Wilson, 2002; Dede, 2000; Jorde, 2003). The idea that using ICT enhances student motivation has gained currency in recent years (Campbell, 1984; Rieber, 1991; Schofield, 1995; Strømme, 2004), hence Schofield (1995) suggests a range of potential reasons such as novelty value, variety from teachers' lecturing, usefulness of ICT-skills later in life, challenge of ICT applications when compared with ordinary school work, differentiation as students are in control and can work at their own pace, and finally, some ICT tools provide rapid feedback.

Studies of the use of ICT in educational settings have focussed on issues like design, change of classroom practice and learning outcome (Clark & Jorde, 2004; Hoffman, Wu,

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Krajcik, & Soloway, 2003; Songer, Lee, & McDonald, 2003; Wasson & Ludvigsen, 2003). According to Erstad (2004), there is a tendency that research on implementation of ICT in schools has moved from a strong technology-based focus, e.g. registering number of computers and amount of time spent using ICT in schools (Kløvstad & Kristiansen, 2004; Quale, 2000; UFD, 2005) towards focussing more on how technology best can be exploited to promote learning. On the basis of a literature review, Webb (2005) argues that ICT-rich environments in science teaching can: (1) promote cognitive development, (2) enable a wider range of experience, so that students can relate science to their own and other real-world experiences, (3) increase students' self-management and enable them to track their progress, so that teachers' time is freed to focus on supporting and enabling students' learning and (4) facilitate data collection and presentation of data that help students to understand and interpret the data.

Lottis (2002) suggests that evidence about the effectiveness of particular technology-based approaches must be gathered, evaluated, analysed and published. Similarly, Crosier et al. (2002) suggest that school-based evaluation studies are important for gaining an understanding of how software is used and integrated in school settings. They further argue that observing students using the software and gathering their opinions of it will ensure that the software is useful, enjoyable and usable by students, and that the educational goals are being satisfied. Such a line of research is followed in the present study on the design of the interactive learning environment *Radioactivity*, from the Norwegian Viten[1] project. The Viten project has connections to the WISE-project[2] (Jorde, Strømme, Sørborg, Erlien, & Mork, 2003; Linn, 2003; Linn, Clark, & Slotta, 2003; Linn & Hsi, 2000) and is developing digital learning materials in science for students in Grade 8–12. Since launching the Viten web-site[3] in 2002, 18 learning environments on various topics are now available with more than 300,000 unique students registered as users by November 2008. *Radioactivity*[4] is one of the most popular learning environments with more than 70,000[5] registered users, and for this reason it is interesting to study this environment more in detail. Furthermore, radioactivity is an issue that is difficult to grasp for many students. Hence, the main focus of this article is to describe and discuss *Radioactivity*.

Radioactivity in schools

Why teach about radioactivity?

Radioactivity is repeatedly mentioned in the media, for instance, regarding consequences of Chernobyl, radon[6] in houses and the radioactive waste from Sellafield[7], a major reprocessing plant which is located on the northwest coast of England. Hence, radioactivity is an area of science that is of continued public interest and concern, and should therefore be addressed in science education. Millar (1994) suggests that from a perspective of 'democratic utility', many people would give high priority to understanding the phenomenon of radioactivity and ionising radiation because of links to such issues as nuclear power and the risks of exposure to ionising radiation. Similarly, Henriksen (1996) points to three main arguments for possessing knowledge about radioactivity:

- *The pragmatic reason*. People should be capable of protecting themselves from the harmful effects of radiation as well as avoiding excessive fear.
- *The democratic reason*. People should be capable of informed judgments in political matters involving radiation phenomena: nuclear energy, waste disposal, exposure limits, etc.

- *The educational reason*. The individual derives pleasure and fulfillment from knowing something about the world around him/her.

Millar (1994) argues that because of the historical role radioactivity played in developing ideas about the structure of matter, the topic has a strong claim to inclusion in the science curriculum, both on 'cultural' grounds and from the more traditional perspective of the logical structure of the discipline. In contrast, Eijkelhof (1996) argues that if the main aim of science education is to prepare students for coping with life in modern society, the purpose of teaching the topic of ionising radiation should be shifted from 'understanding nuclear physics' to 'being able to understand radiation risk information'. He further suggests that this should influence curriculum content and teaching strategies.

What do we know about the understanding of radioactivity? Compared to physics topics like electricity or mechanics, relatively little research has been carried out on students' and the public's conceptions of radioactivity. However, a number of studies regarding understanding of radioactivity have been done after the Chernobyl accident in 1986. One line of focus has been ideas that students and the general public have on radioactivity in relation to information presented in the media (Eijkelhof & Millar, 1988; Lijnse, Eijkelhof, Klaassen, & Scholte, 1990). Lijnse et al. (1990) argue that there is a striking correspondence between student ideas and media information after the Chernobyl accident. They report that many people have an undifferentiated concept of radiation/radioactive matter. People seem to grasp fragments of information from the media and create their own conceptions on radioactivity. Stølsbotn (2002) found that 23% of a sample of the Norwegian population regarded it as true, or probably true, that if someone is exposed to any amount of radioactivity, they are certain to die as a result. A view of radioactivity as something dangerous seems to be quite common. Sjøberg (2004) talks about 'radio-phobia': a fear for all that resembles nuclear physics, atoms and radiation – at least when the radiation is made by humans. He argues that in medicine, for instance, we no longer talk about nuclear magnetic resonance, but rather forget nuclear and use the notion magnetic resonance, which does not sound dangerous, but denotes the same thing (Sjøberg, 2004).

Other studies, across different age groups, nationalities and educational levels, suggest that people have an undifferentiated understanding of concepts like radiation, radioactive material, irradiation and contamination (Alsop, 2001; Henriksen, 1996; Henriksen & Jorde, 2001; Klaassen, 1995; Millar, 1994; Millar & Singh, 1996). Radioactivity is a phenomenon that seems difficult for students and the general public to understand; so what can be done to improve young peoples' understanding of radioactivity?

Approaches to teaching about radioactivity in schools

Radioactivity is taught in secondary school science classes all over the world. According to several researchers (Eijkelhof, 1996; Millar, Klaassen, & Eijkelhof, 1990), the usual approach to teaching this topic has been to start with the structure of the atom and the nucleus, followed by concepts such as half-life, α, β and γ radiation, activity, nuclear fission and fusion. Towards the end of the series of lessons, some applications are usually mentioned, such as irradiation of food and nuclear power plants, whereas safety issues are dealt only superficially. Other ways of teaching about radioactivity have been suggested. Millar et al. (1990) proposed an approach based on research into children's understanding about radioactivity, set in a real-world context with the micro-level explanations at the end of the teaching sequence. Parts of this are followed up in the 21st century science (Holman, Hunt, & Millar, 2004; Millar, 2006). Klaassen (1995) developed a problem-posing approach, not based upon micro-level explanations that have been carried out with positive experiences in a more recent study (Lijnse & Klaassen, 2004). Henriksen and Jorde (2001) reported that visiting a museum exhibition as part of the teaching sequence, provided science learning outcomes for the majority of the students when investigating high school students' understanding of radiation. Crosier, Cobb, and Wilson (2000) developed a virtual environment for teaching about radioactivity , and observed no clear benefits for the virtual environment compared with traditional teaching methods in terms of test scores and attitude ratings (Crosier et al., 2002). The present study also reports on an approach using ICT for teaching about radioactivity. Because of the nature of radioactivity as an 'invisible' phenomenon which is difficult for many students to understand, ICT may serve an important role in making the 'invisible' visible. Many Norwegian schools do not have equipment like Geiger counters and Scintillation counters, and many science teachers have not studied physics and may feel insecure when teaching about radioactivity. Hence, ICT might be useful in providing opportunities for experiments with equipment not available in all schools.

Features of the interactive learning environment *Radioactivity*

In this section, a description of the aims and features of the interactive learning environment *Radioactivity* will be provided. The main aims of *Radioactivity* are identical with the Norwegian national curriculum goals for secondary school science, 10th grade (KUF, 1996)[8]:

> Substances, properties and use:
>
> 'Pupils should have the opportunity to learn about the characteristics of various types of radioactivity, radioactive substances and minerals, and the use of radioactive substances and their usefulness to society set against their health and environmental hazards. Access to software may be helpful in this connection'.

Radioactivity also covers some national curriculum goals for Grade 11 and is based on well accepted, current theory about radioactivity. However, the novelty of the present approach to teaching about radioactivity is the placing of the topic in a context where the students are given roles as journalists with a case to solve. *Radioactivity* is organised in a specially designed learning management content system, with a menu on the left hand side containing various types of activities (see Figure 1).

Table 1 provides a detailed description of the six main units of *Radioactivity* and the features of each unit. The approach chosen in *Radioactivity* connects scientific information that may seem inaccessible for many students, to situations that might happen in their everyday life. When reporting on a fire in a car accident, they discover traces of radioactive substances and pursue the case by collecting information on radioactivity, performing measurements and analyses at the virtual laboratory, and learning how to write a newspaper article with scientific information. The scene of the accident is situated in the mountain area of Dovre, where traces of radioactive substances from the Chernobyl accident are still measurable. When students collect virtual samples, they find traces of radioactive isotopes from Chernobyl. The idea is that students should learn about the consequences such effluents might have on the environment, the geographical range of the effluents, their effects over time and half-lives. Students also detect the radioactive substance Americium, originating from smoke alarms in the cargo of a truck involved in

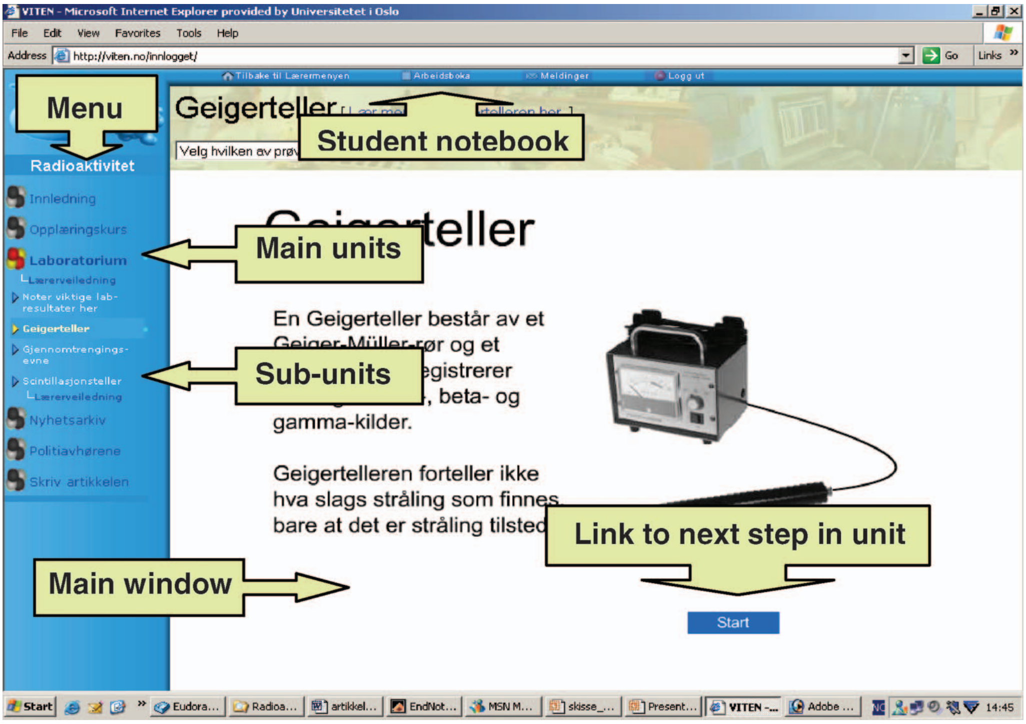


Figure 1. The Viten user interface with the menu on the left hand side including main units[9] and sub-units. Student notebook is available on the top, while various activities, evidence units, simulations etc are available in the main window.

the accident. The purpose is to show students that some types of radioactive substances are useful, and thereby contribute to a more nuanced understanding of radiation. Through simulations and animations in the laboratory, students learn how radioactive substances can be identified. Working on the newspaper article, students are challenged to use their own language in an interactive constructive process to present information according to a real-world situation.

Types of units in Radioactivity

The units in *Radioactivity* have different features, able to be classified as one of the following three types:

(1) Visual unit containing text, pictures and animations.
(2) Interactive unit containing activities like simulations, interactive animations, quizzes and fill in tasks.
(3) Written unit involving written tasks.

To investigate how various components in *Radioactivity* are used to provide information related to the curriculum goals, the content of *Radioactivity* was classified as information about radioactivity as a phenomenon, radioactivity as a resource and radioactivity as a threat. Table 2 illustrates how these content categories and information

Table 1. Description of the six main units in *Radioactivity* and the features of each unit.

Main units	Features
Introduction	
The students are introduced to their mission, which is to take on the role as journalists for an online newspaper. They are going to cover an explosive fire involving a car accident. At the scene of the accident they discover traces of radioactive substances.	Virtual case where ICT makes it possible to create a scene for students to act on. ICT makes the case more realistic by keeping the students in the case through virtual cell phone messages from the editor during their work process. Students can take virtual samples from the scene of the accident. These samples will later be analysed at the virtual lab. Teacher guidance encourages discussion on how many samples are needed and where these should be taken, e.g. the importance of blind samples, marking samples and taking safety precautions.
Training course	
Students are introduced to the basics of radioactivity and the three types of radiation, guided by animations, experiments, written tasks and multiple choice questions.	Animations are used to explain the particle model and the origin and characteristics of α-, β- and γ-radiation. 'Fill in' tasks where students receive immediate feedback, e.g. to practice understanding of atomic formulas. A multiple choice test providing immediate response.
Virtual laboratory	
Students are able to analyse the samples they collected from the scene of the accident by Geiger counter and Scintillation counter. In addition they work in interactive animations of the pervasiveness of the three types of radiation. The objective is to identify the radioactive substances from the scene of the accident.	Virtual samples can be analysed in three ways: (1) by a Geiger counter showing the radiation activity, (2) the penetrating power of radiation types in paper, aluminium, lead and human tissue, (3) defining the radioactive substances in the sample by a Scintillation counter and an isotope table. All tools at the lab are simulations designed as a step by step sequence and supported by text. Cell phone text message from editor with questions and encouragement.
News archive	
Contains recent news involving radiation. Students can also find some factual information that may help them solve their case.	The newspaper articles are fictional, specially designed to support the case in this learning environment.
Interrogations	
Transcripts from interrogations of the involved parties in the accident are available here. These might help students identify the person who placed the radioactive substance in the cargo.	A cell phone text message from the editor reminds the students of their deadlines.
Newspaper article	
Closing activity: the students must evaluate evidence, and complete the mission by writing an online newspaper article. Here they find tips on how to write a factual article and what to include.	Electronic newspaper where students write their article and publish it when accepted by the teacher. Information on the newspaper article genre and critiquing sources is provided.

Table 2. Overview of how the content categories and information related to the case are distributed according to different kinds of units in *Radioactivity*.

	Phenomenon	Resource	Threat	Mixed content	Information related to the case/mission
Visual units	2	1	0	5	12
Interactive units	12	0	0	0	1
Written units	6	0	0	1	1

Visual units: $n = 20$, interactive units: $n = 13$, written units: $n = 8$.

related to the case/mission are distributed according to the three types of units in *Radioactivity*. As shown in Table 2, the majority of visual units are related to information about the case, indicating that a lot of effort is put into developing the case and constructing real-life situations for students.

The classification shows that all but one of the interactive units, and the majority of the written tasks, concern radioactivity as a phenomenon. Only one unit is specifically related to radioactivity as a resource, and no units are specifically related to radioactivity as a threat. However, information about radioactivity as a resource, as a threat and as a phenomenon is mixed on five visual units. Hence, from Table 2 it can be concluded that there is a disproportionate focus on the three content categories in favour of radioactivity as a phenomenon. This is in accordance with how radioactivity traditionally has been taught in Norway, and part of what Millar (1994) refers to as the historical role of radioactivity in developing ideas about the structure of matter.

Animations

To get a more detailed impression of some interactive features of *Radioactivity*, two animations are described step-by-step in the following.

Example 1. What is radioactivity?

Radioactivity as a phenomenon is introduced through animations and interactive tasks in *Radioactivity*. All these animations are designed according to the same principles: each animation is constructed as a step-by-step sequence, where students themselves decide when they want to go on to the next step, or whether they want to revisit an earlier stage. Milheim (1993) argues the fact that learners are sometimes able to control aspects of the animation is a unique feature of animations in computer-based instruction when compared with animation available in other media formats. A detailed description of an example of an animation from *Radioactivity* is provided in Figure 2.

On the basis of a review of research studies on the effects of animation, Milheim (1993) has developed a series of guidelines for implementation of animation within a computer-based lesson or multimedia program. Three guidelines are related to general design: develop simple animations rather than complex ones, design animation presentations so that important information can easily be perceived and include options for varying the speed of an animated presentation. The animation in Figure 2 is in accordance with these guidelines because it is simple, includes options for varying the speed and important information is quite visible. Milheim (1993) also provides content-related guidelines: use

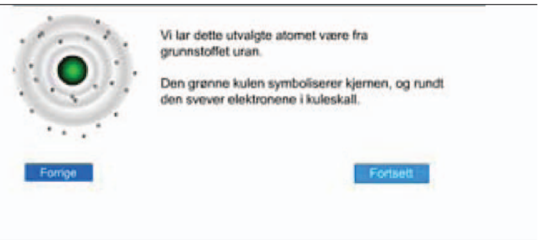
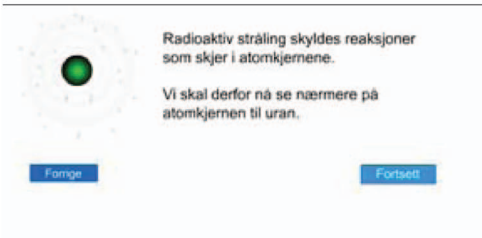
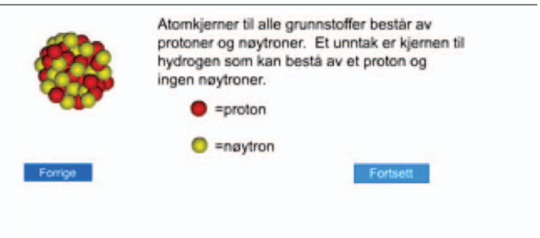
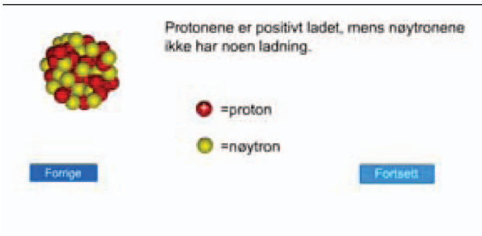
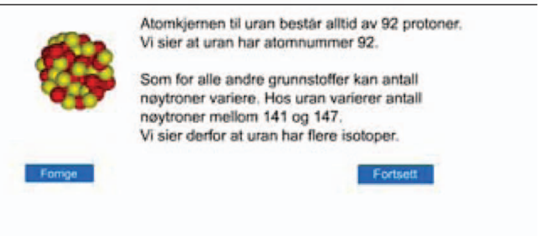
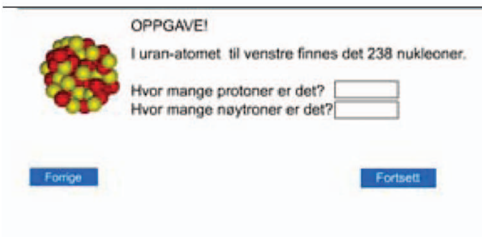
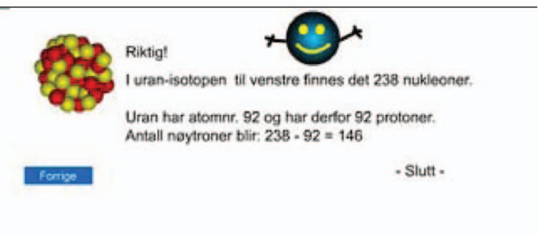
	
Students are introduced to a part of a substance where the animation zooms in on a model of one atom.	A uranium atom is chosen as an example. The green globe illustrates the nucleus with the electrons moving around it. The blue buttons take the students to the next or previous step of the animation.
	
Radioactivity is caused by reactions in the nucleus, so, we shall take a closer look at the nucleus of a uranium atom.	Atomic nuclei in all basic elements consist of protons and neutrons. One exception is the nucleus of the hydrogen atom that may consist of one proton and no neutrons.
	
Protons are positively charged, while neutrons have no charge.	Students are introduced to the formulas of atomic nuclei through the example of uranium. They are also introduced to the concept of isotopes.
	
Students fill in the numbers of protons and neutrons in a uranium nucleus with 238 nuclei.	Positive feedback and a repeated explanation are given when the answer is correct.

Figure 2. Step-by-step sequence of interactive unit on nuclear particles and formulas.

animation that relates directly to important objectives or features within an instructional lesson, use animation when the instruction includes the use of motion or trajectory, use animation when the instruction requires visualisation and use animation to show otherwise 'invisible' events. The animations at each step in Figure 2 are certainly related to the objectives of the lesson; they involve motion and illustrate an 'invisible' phenomenon that may be more easily understood through the use of animation. To summarise, the animation in Figure 2 seems to coincide well with Milheim's guidelines (1993) for implementation of animations. Five other animations in *Radioactivity* are developed after the same principles as the one in Figure 2.

Example 2. The difference between the three types of radioactivity

Information about the three types of radioactivity is provided in several animations similar to the one in Figure 2. In addition, information about the penetrating power of the three radiation types and their effects on the human body is provided in the animation described in Figure 3.

The animation sequence illustrated in Figure 3 is located in the virtual laboratory in *Radioactivity* and followed by an interactive simulation. In this simulation, students cover

The penetrating power of the three radiation types. If students hold their pointer over the α, β, or γ symbol, animated particles or waves representing each type of radiation will appear. α particles will be stopped by the illustrated paper, β particles will be stopped by the aluminium plate and most γ radiation will be stopped by the lead plate. At the same time a piece of text below the visualization explains the animation sequence.

The penetrating power of the three radiation types is visualized on the human body. The animation shows how α- and β particles are stopped by air and clothes and how γ radiation goes through the human body.

This step repeats that α- and β particles from a source on the ground will be stopped by air and clothes. However, it is emphasised and visualized that when a radioactive source has ended up inside the human body, e.g. in the lungs or the intestine the case is different. In contrast to most of the γ radiation, α- and β radiation will now be absorbed in the human body.

Figure 3. The unit on the penetrating power of α, β and γ-radiation.

their samples from the scene of the accident with various materials, and use a Geiger counter to measure the penetrating power of the radiation in each sample.

Discussion

This article has attempted to explore some characteristics of the interactive learning environment *Radioactivity*. In the following section, these will be discussed in light of a set of quality principles for digital learning resources developed by the British Educational Communications and Technology Agency (BECTA). BECTA lists core pedagogic principles and core design principles (BECTA, 2007). The former address the processes and conditions under which successful learning can take place and will be used as reference when discussing features and opinions on radioactivity.

Student engagement

Teaching and learning should engage, challenge and motivate students. Student engagement is emphasised as a core pedagogic principle by BECTA (2007). This entails an experience that is motivating, enjoyable and encourages a culture for learning. In the practical real-world context of *Radioactivity*, the radioactive sources involved have their origin in smoke alarms and radioactive waste from the Chernobyl accident. Roschelle, Pea, Hoadley, Gordin, and Means (2000) put forward connections to real-world contexts, as one of the four key characteristics of successful teaching resources. Other researchers (e.g. Linn, Davis, & Bell, 2004; Webb, 2005) also emphasise the importance of a context which is personally relevant to students, when designing ICT learning environments. *Radioactivity* is designed as a case, where students are journalists with a mission to accomplish. The designers of *Radioactivity* have developed a convincing setting with 12 visual units (see Table 2) containing information that makes the case credible.

Match to the curriculum

It is important that digital learning resources has a worthwhile educational aim and are not simply about occupying or entertaining students. According to BECTA, digital learning resources should have clear objectives, a content that is relevant, accurate, trustworthy and authoritative. Furthermore, the learning activities must be appropriate to the curriculum goals (BECTA, 2007). The goals of *Radioactivity* are identical to those of the national curriculum, an important factor when teachers decide whether to use the learning environment or not (Mork & Jorde, 2005). The present focus has much in common with how radioactivity traditionally has been taught, both in Norway and other countries (Eijkelhof, 1996; Millar et al., 1990). Hence, familiarity with content might be a reason why many science teachers choose to use *Radioactivity* in their classrooms.

In the trade off between elaboration of content and workload for students, the designers of *Radioactivity* seem to have chosen to elaborate more on radioactivity as a phenomenon, at the expense of radioactivity as a resource and as a threat. This choice can be justified by the fact that radioactivity is a phenomenon that can be more easily understood through visualisations like animations and simulations. However, it is a major weakness that *Radioactivity* is not focussing more on the socio-scientific issues concerning radioactivity. The author agrees with Eijkelhof (1996), who argues for shifting the focus of teaching about radioactivity from ‘understanding nuclear physics’ towards ‘being able to understand risk information’.

Effective learning

Another core pedagogical principle put forward by BECTA (2007) is effective learning which can be realised in a variety of ways. For instance, the use of a range of approaches allows the student to choose one that suits them, or that can be personalised for the student, or that will extend the student's repertoire of approaches to learning. The context where students are journalists in *Radioactivity* is an example of providing an authentic situation. As part of being a journalist, students must use knowledge and write their own newspaper article, an activity encouraging higher order thinking. This activity is time consuming because students continually revisit units in the learning environment: reading texts and running animations multiple times (own observations). A closing activity, where students use and rearrange information in their own language and in a new setting, is an important part of the learning process, hence spending time on this activity can potentially influence student learning outcomes.

Furthermore, as shown above, *Radioactivity* has many components, ranging from interactive animations and simulations to multiple choice tests and cell phone text messages popping up during the work process. Several authors have developed guidelines for design, content and use of animations in digital learning materials (Mayer & Moreno, 2002; Milheim, 1993; Rieber, 1990). There is a high degree of similarity between such guidelines and the animations found in *Radioactivity*. Milheim (1993) for instance, suggests that one should develop simple animations where it is easy to perceive important information, and that animations should include options for varying the speed. Most animations found in *Radioactivity* are interactive, and kept without confusing details and additional effects; moreover, the users are in control of the speed. As shown in Figures 2, 3, only the content in focus is on the screen, supplemented by a relatively small amount of text close to the animation, which is in line with Mayer and Moreno's (2002) principle that text should be placed close to the corresponding animation. Some of the features mentioned earlier may seem obvious, but a quick search for animations in educational settings on the Internet will show that this is not the case.

In a study of another learning environment from Viten, students report that it is easier to understand the scientific explanations when they are visualised by animations and text guiding them through the content step-by-step (Strømme, 2004). It is also reported that animations make it easier to remember the content and more motivating to learn science (Hennessy, Deaney, & Ruthven, 2006; Strømme, 2004).

Assessment to support learning

In order to support learning, teaching and learning should incorporate a formative assessment of what has, or has not, been learnt or understood. This includes providing feedback to the students on their acquisition of knowledge and skills (BECTA, 2007). *Radioactivity* contains a multiple choice test and other activities providing immediate feedback (see Table 1). However, feedback does not need to be limited to the provision of tests. It can also be achieved via tasks like writing the newspaper article, where students themselves, in a kind of self-assessment, realises that they need to revisit some units to be able to solve a particular problem.

The teacher role

Central to the core pedagogical principles mentioned earlier is the assumption that the quality of a digital learning resource does not determine the quality of learning and teaching, but underpins and contributes to it. The quality of the learning experience is not inherent in the digital learning resource itself, but in the decisions and behaviour of teachers (or students when they are in control) in their planning and preparation of the learning experience, and in the decisions and behaviour of students during the learning experience (BECTA, 2007).

Learning materials from the Viten project are intended to serve as supplement to other science teaching approaches, providing a wide variety of tasks and activities on traditional science themes or socio-scientific issues. In *Radioactivity*, teachers can choose to let students solve the actual case, but they are free to use the whole or parts of the learning environment in whatever way they want. For instance, it can be observed on the Viten server that many students skip writing the newspaper article. In a survey amongst teachers using learning resources from the Viten project, many teachers report that they choose to not use the newspaper article at the end of *Radioactivity* because it is time consuming and they consider it a language task (unpublished material). As with textbooks and other teaching resources, there are numerous ways of implementing digital learning materials in schools. Squire et al. (2003) argue that because all classrooms are unique, it is ultimately the responsibility of the teacher to adapt curriculum materials to fit their own strengths, needs and goals, and also the goals of their students.

Conclusions and implications

Digital learning resources should exploit the opportunities provided by ICT to enhance learning and teaching. According to BECTA (2007), this can be done by offering clear benefits over non-ICT resources such as providing appropriate educational stimulus and feedback, enabling collaborative work where appropriate, supporting the user in customising the resource, using an appropriate mix of media for the learning objective (for e.g. graphics, animation, photographs, video, sound) to engage the learner with the educational purposes, and providing record-keeping facilities for the practitioner and learner.

As revealed in this study, the strength of *Radioactivity* is the units focussing on radioactivity as a phenomenon, which are well designed, interactive and followed-up by written tasks. The features of the animations in these units are in line with recommendations from the literature about what is regarded as good quality animations with a potential to promote learning.

Radioactivity also has its weaknesses, in terms of a less elaborate focus on radioactivity as a resource and as a threat. Good teachers will compensate for these limitations by drawing on other learning materials, in addition to *Radioactivity*. The wide range of activities and tasks included in *Radioactivity* might be a reason why the learning environment is easy to adapt locally. When teachers are more familiar with digital learning materials like *Radioactivity*, we shall probably observe more creative use of such resources, for instance, combining the digital resources with experiments, excursions and other offline activities in the classroom. An interesting line of research will be to investigate how individual teachers customise the implementation of learning materials like *Radioactivity* in their science lessons.

The designers of *Radioactivity* may want to consider some changes in future versions of the learning environment. For instance, it would probably strengthen *Radioactivity* if remedies from the animations, interactive and written tasks regarding radioactivity as a phenomenon were used to elaborate more on radioactivity as a resource and as a threat: e.g. interactive units on how ionising radiation is used for medical purposes like X-rays and cancer treatment. Likewise, there could have been more focus on radon, the single source providing the largest radiation dose to most Norwegians, and an issue that the World Health Organisation is most concerned about. More elaboration on how nuclear power plants work, and how radioactive waste from these is handled would also improve *Radioactivity*. One of the major advantages about ICT and digital learning materials is that the materials can easily be changed to better fit their purpose.

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Notes

1. The word 'viten' means 'knowledge' in Norwegian.
2. http://wise.berkeley.edu
3. http://viten.no
4. Radioactivity is available in Norwegian and Danish, but the following learning environments are also available in English: http://globalwarming.viten.no/, http://northernlights.viten.no/, http://genetechnology.viten.no/
5. A high number in a country with 4.6 million inhabitants and about 60,000 students in each cohort.
6. In June 2005, the World Health Organisation (WHO) raised the alarm that radon is the second most common reason for lung cancer after smoking. Norway has the world's highest concentration of radon indoors.
7. The content of the radioactive discharges from Sellafield can be traced from the Irish sea north to the coast of Norway and up to the Barents sea, reaching as far north as Spitsbergen. The largest concentrations of radioactivity may be found along the coastline off the Sellafield site itself. Radioactive contamination has been traced in shellfish, fish and seaweed, to ocean water, sediments on the bottom of the Irish sea and in sand on the beaches.
8. A new national curriculum was launched in Norway in 2006, placing radioactivity only at Grade 11.
9. A unit is defined as a link that is found in the navigation menu of radioactivity. Each unit may have several steps, and the work load varies between different units.

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