EDEN - 2011 Open Classroom Conference
October 27 - 29, 2011
Ellinogermaniki Agogi, Athens, Greece

Augmented Reality in Education

Proceedings of the "Science Center To Go" Workshops

Science Center To Go

EACEA
Education, Audiovisual & Culture Executive Agency

Education and Culture DG
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Preface

Visualising the invisible has been one of the most fascinating phenomena for humans during the history. It matters as well the scientific researchers as the non-scientists. Microscope, telescope, x-rays, or brain scanning have had a huge impact in development of scientific research. In addition, these innovations have dramatically changed the whole vision of our world with a great impact for the public understanding of science.

The Lifelong Learning project “Science Center to Go” (www.sctg.eu), supported by EU, focused on using the principle of making the invisible observable by Augmented Reality [AR] technology application in science education. The long tradition of learning by doing started by John Dewey more than one hundred years ago was brought into the most modern information technology context. Interactive science centres have become important players in science education worldwide. The hands-on solutions of these science centres have been also an inspiration of this project. Now, an European network of science centres, universities, R&D companies and researchers developed new Augmented Reality -based educational solutions for teacher training in co-operation with teacher education intsitutes, schools, and educational administrations linking formal education and informal learning. The objective to identify key elements within the curricula in different countries in order to teach about the scientific research process using learning to make observations was clearly obtained according this report.

Science Center to Go –project created an implementation of Augmented Reality (AR) technology in science education. While this technology up to now mainly is used by very special users such as the military and high-tech companies, this project gradually converted it into wider educational use. By applying the leading evidence-based education methods related to Inquiry Based Science Education, selected learning scenarios were created to be used by hundred of teachers, students, and science centre educators. The project offered challenging small-scale exhibits, which were brought from science centres to schools. This enabled teachers and students to experience hands-on science by actively manipulating the experiments, thus delivering natural ways of active playful learning.

According to the evaluation and educational research conducted during Science Center to Go –project, following results were achieved: 1) with AR it is possible to combine real objects with virtual ones and to place suitable information into real surroundings; 2) the possibility of AR to make convergence of education is challenging as the technology optimises and expand; 3) the project implements augmented reality tools that visualising the invisible (forces, fields) by projecting virtual objects onto a real experimental setting. 4) the AR-system allows students to interact physically and intellectually with instructional learning scenarios materials through “hands on” experimentation and “minds on” reflection; 5) as the result of this inquiry, the pedagogical experts and teachers attending the process underlined as the main elemen moving from teachercontrolled learning to student orientated learning with context-related knowledge; 6) the usability, availability and the prices of this AR-technology are making it soon available for everyday education routines; 7) the threshold is no more money or technology, but mental resources.

Lifelong learning needs new practical forms, and the formal education can learn something from the informal, open learning environments. The results of Science Centre To Go –project indicate and encourage for further development of Augmented Reality educational solutions. Meaningful learning has two components. First, the content should be meaningful for the learner. Second, the learning process should be arranged pedagogically in a meaningful way (according to the age and the former knowledge and skills of the learner and by the logical structure of the topic to be taught.) All the great innovations in education have been based on putting these two principles into practice.

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The “Science Center To Go” project

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Abstract

Over the last decade the rapid evolution of technology applications has yielded new ways to develop applications and approach learning. Augmented Reality (AR) is such a technology that offers a new educational approach in helping learners develop critical capacity and deeper understanding of the concepts underlying scientific investigation. In addition, AR enriches the repertoire of learning opportunities and helps meet the challenge of “science for all”, i.e., providing science education opportunities tailored to diverse and heterogeneous populations.

The “Science Center To Go” approach aims at the presentation of such AR technology initiative in science teaching both in formal & informal educational environments that facilitates lifelong learning by offering to learners the opportunity to gain exposure to everyday science in a way that is appropriate to their individual level of understanding.

Keywords

Augmented Reality, Inquiry-based Science Teaching, Informal education.

1. Introduction

There is sufficient evidence to suggest that both the persistence and the quality of learning are highly enhanced when the potential learner is actively participating in the learning process [1, 2]. Science Centers adopt this philosophy by offering intriguing exhibits that enable their visitors to experience science first hand by actively manipulating the experiments, thus delivering natural ways of active playful learning. Modern technologies like Augmented Reality (AR) are often used to enrich the experience and display otherwise hidden phenomena. However, experiencing augmented reality requires visiting the Science Center.

The Science Center To Go (SCeTGo) approach goes one step further and aims to bring similar comprehensive learning experiences out of the Science Center into a school’s classroom and/or everyone’s home. Its miniature exhibits - by “fitting into a pocket” and operating with ordinary hardware - enable learners to experiment whenever and wherever they please. This way the consortium makes full use of the powerful capabilities offered by tailor-made exhibits combined with AR.

2. The SCeTGo approach

The SCeTGo project aims to bridge the gap between formal & informal education, to promote science learning at all levels, and to assist in ensuring that science not only holds a high place in teaching curricula but also promotes creative problem solving and learning-by-doing. The overall objective, through the exploitation of AR, is to integrate experiential learning & supporting materials provided by scientists & educators into a comprehensive knowledge base for learning open to the public.

Figure 1 The Science Center To Go suitcase and contents (laptop not shown)

SCeTGo's approach is based on an educational kit that is delivered in the form of a small suitcase (Figure 1) and contains a tablet, a web camera, a series of 3-D printed miniatures and a user guide. These miniatures combined in various arrangements can form in total five mini- exhibits that illustrate various physical phenomena linked to secondary school curricula: sound wave propagation, rigid body (double cone) motion on an inclined plane, wing dynamics, wave-particle duality and gas particles' velocity distribution. Learners can interact dynamically with the miniature exhibits and by using AR enrich their optical view with information relevant to the physical phenomena shown. Examples of the physical phenomena include explanation of why do planes fly and why does the siren sound of a fire truck is different when it approaches an observer than when it moves away from him.

In the framework of the project the SCeTGo partnership has developed, implemented and evaluated a series of learning activities in accordance with the current trends in science education, based on inquiry and problem based approaches that allow the actively participating learners to enhance their scientific literacy and critical thinking skills. Educational scenarios following the inquiry-based teaching methodology have been designed for all miniature exhibits. These scenarios by making use of AR introduce new ways of interaction between learners & the real world.

In general, SCeTGo demonstrates to learners through the merging of the miniature exhibits and the AR technology new ways of interacting with scientific concepts and phenomena. A detailed description of all five SCeTGo exhibits enriched by images and videos can be found at the project's official website [3]. A snapshot of this website is shown in Figure 2.

Figure 2. The SCeTGo website: www.sctg.eu

It is beyond the scope of this paper to provide a technical overview of the AR-system or a detailed description of the SCeTGo miniatures and the way they are integrated in a formal and/or an informal educational environment. All this information can be found in the other SCeTGo papers within this volume along with the general evaluation of the project's approach and the assessment of the impact on quantum understanding by using SCeTGo's double slit miniature. The latter study has been performed to senior high-school students in Greece.

In the sections to follow emphasis is given on the innovative character of SCeTGo and the potential impact it can have in education and society.

3. Innovative Characteristics

The SCeTGo introduces an ICT-enabled learning approach that has the following innovative characteristics:

a) Makes use of advanced visualization technologies (AR) that not only have the potential to enrich the learners' optical view with relevant information but also allow the learners to interact dynamically with the miniature exhibits

b) Is easy to operate. As it is based on common devices there are no real obstacles that a potential learner has to overcome in order to use the system.

c) Promotes an inquiry-based and experiential learning approach. Learners experience science first hand at their own leisure and engage in activities where information is discovered by them rather than passively transmitted to them. By interacting with the miniature exhibits learners can not only visualize invisible physical quantities but can also control the conditions that need to be met in order for a phenomenon to occur (e.g. learners by rotating a miniature wing, namely the mini-wing exhibit shown in Figure 3, at different angles can see through the airflow augmentation on the wing, why planes fly)

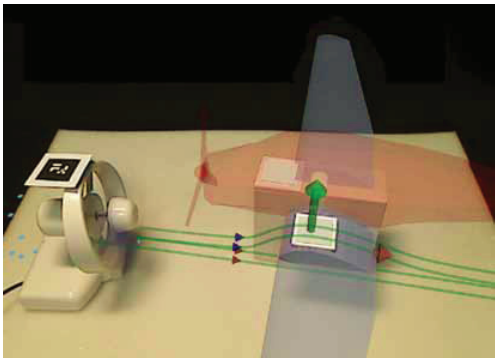

Figure 3. The mini-wing as it appears on the laptop's screen

d) Demonstrates the possibilities that students will experience in the future during their educational training in respect to AR technological applications.

e) Promotes the importance of science to all European citizens through a journey of entertainment & learning.

f) Contributes to the development of a new generation of citizens who are scientifically literate and thus better prepared to function in a world that is increasingly influenced by science & technology

g) Offers a modern science centre experience outside the walls of the science centre in school classrooms.

4. Impact in Education & Society

The SCeTGo miniature exhibits illustrate various physical phenomena enabling learners to visualize the invisible through AR technology. Thus, they offer to science teachers the opportunity to introduce new approaches in the classroom by using the new customized AR tools and to students the opportunity to use innovative technology in the framework of their normal school curriculum. Moreover the SCeTGo project contributes to the access to and sharing of advanced learning resources not only between schools but also among science centres and universities. In this way it supports the provision of key skills to the future citizens & scientists (collaborative work, creativity, adaptability, intercultural communication).

From the other hand the SCeTGo approach facilitates lifelong learning as it aims to improve quality of learning by providing access to resources (mixed reality tools) with significant educational value and to reinforce the contribution of lifelong learning to social cohesion, active citizenship, intercultural dialogue, gender equality and personal fulfilment. These are major priorities of the EC's Lifelong Learning

Programme which support the development of innovative ICT-based content, services, pedagogies and practice for lifelong learning. Furthermore, the SCeTGo approach helps learners to develop critical capacity and deeper understanding of the concepts underlying scientific investigation. In this framework, the objective of SCeTGo is not solely to produce more scientists and technologists; it is also to produce a new generation of citizens who are scientifically and technologically literate.

Finally, SCeTGo project is aiming at promoting population's interest in science by building on the strengths of both formal educational settings (e.g. secondary schools) and informal learning environments (e.g. homes, science centers and science museums).

5. SCeTGo Events

Over the last two years (2010 & 2011) the SCeTGo approach was either implemented (through workshops, trials etc.) or disseminated (through conferences, seminars etc.) in 126 different type of events in more than 12 countries around Europe.

Major dissemination events included in

a) Germany: the "Girls day Bundeskanzleramt" in Berlin in the mid-April, 2011 (Figure 4).

Figure 4. Mrs. Angela Merkel Chancellor of Germany visiting the SCeTGo stand in Berlin.

b) Belgium: the Scientix European Conference in Brussels in May, 2011. SCeTGo was one of the twenty-five 'EU projects on Science Education for Teachers' showcased throughout the whole duration conference (Figure 5)

Figure 5. Presentation of the SCeTGo project during the Scientix European Conference

c) Poland: the ECSITE Annual Conference in Warsaw on the 25th of May, 2011.

d) Iceland: the Nordic Science Annual Meeting in Reykjavik near the end of September, 2011.

e) Greece: the "Pathway to Inquiry-based Science Teaching" International Summer School in Heraklion in the first week of July, 2011.

f) Sweden: the NO-Biennalen Conference in Halmstad with 300 science teachers

Despite the fact that the SCeTGo project after participating in many events has approached the end of its EU funding period, the SCeTGo partnership will continue to establish contacts with current or former projects under other similar national or European actions in order to continue to reinforce bilateral collaborations and synergies arising for all participants.

6. References

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Pedagogic Issues and Questions from the Science Centre to Go, Augmented Reality, Project Implementation

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Abstract

This paper discusses the teaching and learning issues we have encountered during the Science Centre to Go (SCeTGo), an EU EACEA project. The project was about the development of a set of miniature apparatus overlaid with augmented reality (AR) elements, to support inquiry-based learning in science. The focus of this paper is on teacher acceptance, support for inquiry-based approaches and how students might learn with AR-supported resources. The project has been at the development stage. Therefore widespread classroom implementation has not been part of the project. This paper addresses the future research questions we have derived from the development process that can be pursued in a wide-scale pilot implementation.

1. Introduction

Science Centre To Go (SCeTGo) is an EU EACEA funded project that has researched and developed creative, computer-mediated, resources intended to promote inquiry-based science education (IBSE) using augmented reality (AR). The system consists of a suitcase of five miniature exhibits (miniatures) together with the technology for overlaying live images of the exhibits with visual and auditory elements, in order to explore the underlying scientific phenomena (Figure 1 and 2).

Figure 1: The AR adds elements to the image of the miniature exhibits (double cone)

The system has been piloted in education establishments in several European countries (Germany, Finland, Greece, Romania, Spain and UK). In this paper we discuss some of the educational issues that have arisen.

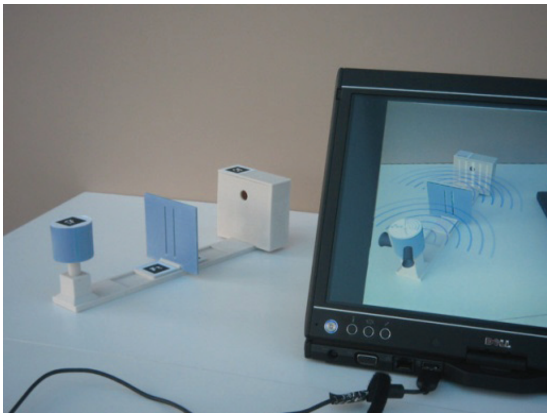


Figure 2: The AR adds elements to the image of the miniature exhibits (double slit)

The exhibits are mini-fire truck, mini-double cone, mini-wing, mini-double slit and mini-cooler & heater (presented on Figure 3):

- Mini-wing (wing dynamics): model of an aeroplane wing that can be rotated. The AR adds in lines indicating the direction and relative speed of airflow over the wing at different orientations, and the uplift and drag. Different shapes of wing can be compared.
- Mini- fire truck (the Doppler effect): model of a fire engine and an observer/ microphone. As the vehicle and microphone move relative to one another the AR adds in the sound of the fire engine, an exaggerated visualisation of the sound waves and their emitted and received frequencies.
- Mini-double-slit (quantum mechanics): the model uses AR to simulate the behaviour of particles and waves passing through single and double slits. It also facilitates the exploration of the phenomenon of wave-particle duality.
- Mini-double cone (classical mechanics): a model of a double cone that appears to travel up sloping rails. The AR assists in an investigation of why this happens by measuring angles.
- Mini-cooler and heater (kinetic theory of gases). The miniature is a temperature probe, mini fridge and a mini heater. The AR shows how the speed of air molecules is related to their temperature.

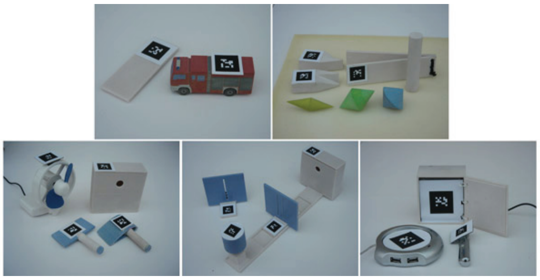


Figure 3: The miniatures: mini-fire truck, mini-double cone, mini-wing, mini-double slit and mini-cooler & heater

2. The Scope of the Project and this Paper

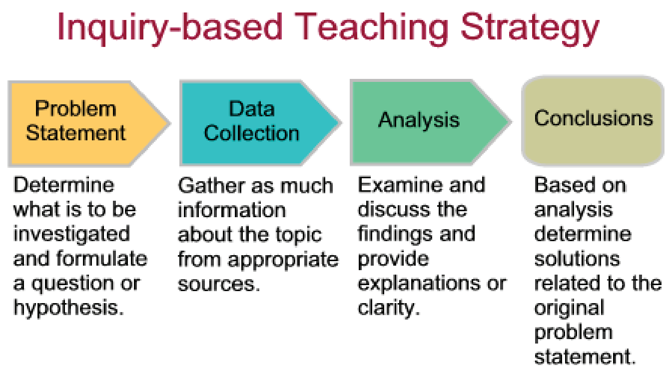
The project has been resourced as a design and test activity. During the project we have only had two sets of prototypes to share amongst the partners for demonstrating and testing. This has been sufficient to get realistic feedback on the usability and reliability of the devices and, more significantly, on the acceptability and interest from teachers and other professionals in the field. The feedback has been very favourable to the development of the SCeTGo resources. The findings of this evaluation are discussed more fully in another paper in this workshop [1].

This paper focuses on educational research and development questions that have emerged from both engineering the prototypes and through the field evaluation and dissemination processes that have included practical engagement and conversations with teachers and students. The paper reflects a development on from the project's deliverable D2.1: SCeTGo Pedagogical Framework and builds on the understanding and questions we present there. Furthermore, it points to the questions we still need to study further in both the application of augmented reality and the use of information technology resources in the pedagogy of IBSE. There are three major areas that we identify for further and deeper research. The first relates to teacher professional development with respect to IBSE and technology; the second refers to classroom implementation and final relates to the student learning with augmented reality.

3. Inquiry Based Science Education

The Rocard Report for European Commission recommends renewal of schools' science-teaching pedagogy by "introduction of inquiry based approaches in schools" ([2]: 22). IBSE is rooted in the scientific method of investigating phenomenon in a structured and methodical manner. Related to teaching and learning, it is an information-processing model that allows students to discover meaning and relevance to information through a series of steps that lead to a conclusion or reflection on the newly attained knowledge. The report also suggests that IBSE can provide increased opportunities for cooperation between actors in the formal and informal arenas.

In most cases of IBSE, teachers use a "guided inquiry" method to facilitate the learning experience and structure the inquiry around specific goals of instruction. The benefits of inquiry-based learning include the development of critical thinking, creative thinking, and problem solving. The process from a teacher's point of view is described in figure 4.



source: http://www.worksheetlibrary.com/teachingtips/inquiry.html
Figure 4: Teacher perspective of inquiry-based learning

Further, [3] suggests a model that contrasts teaching/learning strategies on a matrix (Figure 5).

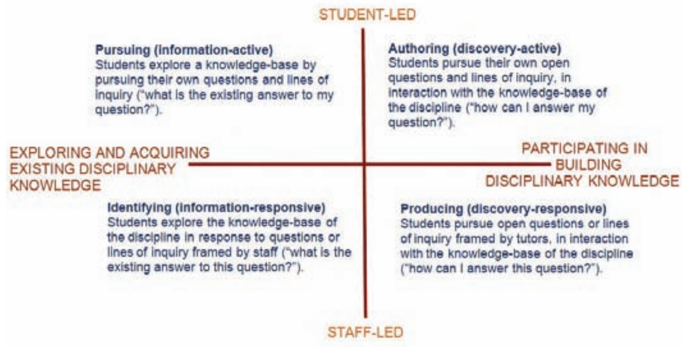


Figure 5: Inquiry-based Learning: Conceptions and Approaches (Levy, 2009)

Levy's framework describes inquiry-based learning in terms of whether the tasks are allocated by the teacher (staff-led) or whether the learners formulate questions themselves (student-led). As learners develop skills of scientific inquiry they should move towards student-led inquiry. Within SCeTGo teachers can encourage learners to compose questions that can be answered either by using the software or by further research.

Building on the work of Bruner [4] and Taba [5] we outline a scenario for discovery-based, or inquiry-based learning:

1. Confront learners with a problem that initially baffles them.
2. Prompt to utilise previously acquired knowledge and perception to recognise ways to tackle the problem.
3. When learners have solved this problem, present them with another one in which they can demonstrate the principles they have now acquired.

SCeTGo fits into this scenario very well. We ask hard questions. Why do planes fly? Why does a fire engine sound different when it's moving towards or away from you?

A more recent analysis divides inquiry-based learning into two types (see [6]):

- finding out information from existing knowledge, the "information frame"
- building and evaluating new knowledge, the "discovery frame".

Both of these frames can be relevant to SCeTGo but the initial focus is on the discovery frame. The learners can be encouraged to be real scientists and to find out something using the miniatures and the AR that they did not know before. They can then judge whether this fits in with their pre-existing perceptions, for example, "objects do not roll uphill" or "light is a wave."

In SCeTGo the information frame would normally come into play after the encounter with the miniature, if the intention is to follow up the activities with further research into existing disciplinary knowledge. It is important that the learners have not studied all of the theory, appropriate to their level, behind the miniatures before they see them, so that there are still opportunities to learn by discovery. For example, younger learners may have learned about the observable properties of sound but they may not know that it travels in waves. So one challenge for them would be to say what they thought the lines represented on the mini-fire truck AR.

A possible exception to this general principle is that learners could find out beforehand how scientists work, for example how they make incremental changes and how they formulate hypotheses and then test them. This would be a useful strategy if the learners are not familiar with scientific and laboratory techniques.

4. Augmented Reality and Learning

Augmented Reality (AR) is a term describing those technologies that allow the real-time mixture between computer-generated digital content and the real world [7]. AR can also be defined as being an overlay or superimposing of digital data visualised on top of the real view of the surrounding environment. From a technological perspective, AR is often related to wearable computers and overhead monitors [8]. People usually associate AR with expensive hardware that requires significant processing capability that can be found only in research and specialist environments such as fighter pilot's cabins. However, nowadays we can witness a wide variety of AR alternatives that can be implemented by much simpler solutions, such as a laptop and a web camera or even with the use of a PDA or a mobile phone (for example http://www.wikitude.org/).

In recent years, with the rapid advances of wireless and mobile technologies, experimenting with AR has moved beyond expensive military applications and has now entered a wide variety of domains. In the field of education, AR has been widely researched in laboratory settings and more recently various tests in real classrooms have been made [8, 9, 10]. By using AR technologies it is possible to combine real objects with virtual ones and to place suitable information into real surroundings. Novel uses of AR application make it possible to converge the fields of education and entertainment, thus creating new opportunities to support learning and teaching in formal and informal settings [11]. Natural or historical events and characters, reconstructed monuments or archaeological sites could be now simulated and augmented to the real world. AR is a booming technology that attracts more and more attention from HCI (Human Computer Interaction) researchers and designers. This allows for the creation of meaningful educational experiences that are grounded in a substantive subject area of knowledge and focus on the intellectual and emotional development of the viewer. From these latest perspectives, AR learning environments have the potential to offer both educational and entertainment value.

Previous research efforts in the field show that AR can have a great potential in education. Construct3D (www.ims.tuwien.ac.at/research/construct3d/) is a tool for exploring and learning about geometry. It takes aspects of computer-aided design (CAD) and combines it with AR technology to create a learning tool aimed to promote social interaction in the shared space, allowing its users to communicate with each other in a natural way [12]. Construct3D was mostly used in an experimental setting, requiring personnel doing maintenance and technical support to run. One key finding from the project was that in order for the AR application to be used for learning, it needed to be seamless and transparent; allowing the user to focus on the actual task rather than the application itself. In line with the constructivist theory of learning, it is good for students to have the opportunity to explore on their own or in collaboration with others, however some guidance might be required or the task at hand might be too hard to understand.

Research efforts regarding earlier uses of AR in education show that in classroom settings students' work more effective together if they can share a common workspace, something that can be difficult with the traditional desktop computer-based education [13]. By using AR applications based on a tangible interface metaphor, physical objects can have virtual information tied to them, allowing students to control it in an intuitive way and collaborate and communicate in a more natural way within the physical environment. One conclusion is that educators and researchers should work together in order to explore novel uses of these technologies in educational situations in which "visualizing the invisible" becomes central for trying to explain difficult phenomenon.

The Human Interface Technology Laboratory in New Zealand (HIT Lab NZ, www.hitlabnz.org/wiki/Home) developed a number of AR applications for educational exhibits aiming to be used in a Science Centre setting (Woods et al., 2004). Based on the observations concerning the used of these applications, the authors have identified a number of possible educational benefits regarding the use of AR technology. The advantages relate to: "being safer and cheaper to reproduce; they can be animated, respond to the users actions, be modified and transformed, be combined seamlessly with other media (audio etc) and they are not constrained by the laws of physics (unless that is desirable)" [9].

Whilst the disadvantages related to lack of familiarity of using such apparatus and the technical obstacles, including the viewing environment, which were yet to be overcome in 2004.

In UK, the learnAR project (www.learnar.org/) has developed a package of ten Augmented Reality curriculum resources that teachers and students can explore in various environments.

AR solutions have been used in a flexible way, to allow a teacher to make demonstrations to a whole class. The same technology can be used by students in a class through laptops, netbooks and desktop computers or, most importantly, by students exploring independently at home. No extra software is needed, just access to the Internet and a printer. However, the project relies heavily on overlay and presentation of information and has very little focus on supporting inquiry-based learning.

The ARiSE project [14] aims at using AR in a school environment. It combines physical and virtual objects and lets users collaborate in close vicinity to each other or to a remote location to manipulate virtual objects relating to their local culture. In this project, different aspects of AR were identified and the preliminary findings indicated that the proposed solution has been well received by students and teachers, and is well suited for remote collaborative learning.

In the AR Volcano Kiosk exhibit (www.hitlabnz.org/wiki/AR_Volcano) the eruption of a Volcano is displayed in interactive animated 3D, something that could be very hard to communicate using a traditional book. It demonstrates how AR provides spatial and temporal support to the learner.

Based on the preliminary findings of the projects described in this section, the impact of AR in education can be summarized as follows:

- Supports inquiry-based and collaborative learning.
- AR technology can add excitement and entertainment to the learning activities, thus increasing motivation among participants of the learning experience.
- AR technology is well suited for demonstrating spatial and temporal concepts and it provides advantages over traditional media.
- AR has the possibility to offer contextual benefits, being able to compare different objects, which also can be in context of the real world. A user can, for example, hold different models in his/her hands and compare them.
- AR could be used as a ground for supporting constructivism. It can allow students to explore information about the surrounding environment at his/her own pace, and to construct his/her own knowledge.

Overall, Augmented Reality provides powerful contextual, situated learning and explorative and discovery learning experiences that may help to connect "new layers" of information in the real world. From a different perspective, the combination of physical and computational media allows moving the interaction beyond the computer screen and offers new opportunities for interaction between the virtual and the real world in novel ways. One major benefit of doing this is to provide different ways of thinking about the world from interacting solely with digital representations or solely with the physical world. The purpose of providing this kind of multiple representation is to provide a link between the abstract data and the physical activity of collecting it, in a way that enables learners to reflect on how the different combinations of the variables they have been measuring or aspects they are investigating affect these latest processes. The visualizations of these phenomena also provide a sense of personal relationship with the data. This can facilitate learners' ability to recall what happened for the various projected data points connected to their experimentation and observation. Having a more intimate relationship with the abstract data, in the sense of knowing how they were physically created, may trigger strong associated concepts related to complex learning [15].

In order for AR applications to be widely adopted in education, it would be fair to assume that the technology needs to be easy to use for the average teacher/educator. Some projects that heavily rely on experimental/complex technological solutions will be hard to implement in schools mainly because the need for special education and training. This is likely to change in the very near future, as wearable computers and mobile devices, as well as AR applications are becoming ubiquitous. Currently, there are a couple of AR authoring tools that appeared in the last years and can be characterized by its relatively easy to use. These applications required actually no more than a standard PC computer and a webcam to function and more information about them is available at ARSights (www.arsights.com/) and BuildAR (www.hitlabnz.org/wiki/BuildAR).

5. The Limits and Future Questions of the SCeTGo Educational Research

It must be noted that we are at an early stage in developments. SCetGo's activity is the development of a set of resources and testing its acceptability. We built two sets of prototypes that were shared between all the partners. Work with teachers and students was by and large confined to, at best, a few hours exposure, with limited opportunities for teachers to develop their practice with the resource. How teachers will behave when they have more access and have time to use the resource for their students' learning can only be surmised. Our findings are based on the response to questionnaires on their expectations of SCeTGo. However in many cases we have had opportunity for informal conversations with teachers and some students, as well as making informal observations on the apparatus in use. We also have had (as experienced teachers ourselves) exposure the resources and have formulated our own critical questions. It is this limited, but very useful exposure that has allowed us to formulate significant research questions in relation to SCeTGo, both in the field of IBSE and learning with AR models.

5.1. The SCeTGo Experience 1: Teacher Acceptance

In preparing for our development and implementation of SCeTGo we undertook desk research, which is published as our Pedagogical Framework. In this document, in addition to the discussions about inquiry-based learning and the educational uses of AR as discussed above, we reiterated the concerns in the literature about teacher readiness. In particular we draw attention to the work of Ilomäki [16] who underlined that students "have the skills to use new kinds of applications and new forms of technology, and their ICT skills are wide, although not necessarily adequate" to the educational context, as they might have inadequate or even wrong working habits. Furthermore "the large majority of teachers have sufficient skills for everyday and routine working practices, but many of them still have difficulties in finding a meaningful pedagogical use for technology". However, Ilomäki concluded that "teachers' good ICT competence helps them to adopt new pedagogical practices and integrate ICT in a meaningful way".

Another challenge in the use of technology in teaching and training could be the tension between learning the subject matter or argument and the simultaneous technical mastery of the technological tool (e.g. the software). Barab et al., [17] show examples on how the inability to use the tool interferes with his ability to perform tasks and thus might negatively impact the understanding as the focus of attention of the learner is shifted from the content to the technology.

Our document cites the European SchoolNet report [18] which identifies several barriers to ICT uptake in schools: Teachers' poor ICT competencies, low motivation and lack of confidence in using new technologies in teaching are significant determinants of their levels of engagement in ICT. These are directly related to the quality and quantity of teacher training programmes and continuing professional development. Furthermore, school-level barriers such as limited access to ICT (due to a lack or poor organisation of ICT resources), poor quality and inadequate maintenance of hardware or unsuitable educational software are also defining elements in teachers' levels of ICT use.

Our preliminary work with teachers throughout the project in a diverse range of educational contexts across six different member states seems to confound much of the literature on teacher uptake of ICT in their teaching. Consistently there has been a high level of acceptance of SCeTGo and expressions from teachers that they wanted to use the resources. There is also a high level of acceptance from students questioned (see the parallel paper from Larsen et al. about SCeTGo evaluation results). This suggests that when we are in a position to implement SCeTGo more widely there might be widespread adoption. Why this contrasts with the warnings in the literature about the uptake of ICT needs further investigation and suggests a major research question for our future work.

5.2. The SCeTGo Experience 2: IBSE and Teaching

In addition to the characteristics of IBSE we have outlined we can simplify the order of activity in IBSE:

- Question(s) related to the topic of inquiry are explored (problem statement).
- This is followed by an investigation and gathering of information related to the question (data collection).
- This followed by a continuing with a discussion of findings (analysis).
- Then there is a process of reflection on what was learned (implications/conclusions).

Thus the first step in any inquiry is the formulation of a question or set of questions related to the topic of inquiry. The question can be posed by the teacher or by the learner(s). Sometimes the question is referred to as a hypothesis or a problem statement.

Once a question is posed, students are encouraged to investigate the topic by gathering information from sources that either the teacher provides or from learning resources or tools that are readily available to them. When enough information related to the topic of inquiry is gathered, it is organized in categories or outlined by highlighting the important information relative to the topic. This helps the students to make connections with new learning and prior learning.

The information is discussed and analyzed for further understanding. The teacher can direct the discussion and highlight the implications that arise from the investigation and show how it relates to the solution of the problem.

Conclusions are made and related back to the original question. Student reflections are encouraged and serve as a way to relate back to the inquiry and retrace the steps that led to the conclusion. This also serves to reinforce the model so that students can repeat the process in any problem-solving situation.

The expectations of use of SCeTGo in the learning situation would map onto this sort of teaching methodology or onto an even more inquiry-based model. This remains a major research question for the project team. Our project has been about resource development rather than classroom implementation and the project is in advance of that stage of implementation. Given the small number of resources (two SCeTGo suitcases) finding answers to issues of classroom practice is limited. However within future work we would want to research the ways teachers use SCeTGo in realistic scenarios.

The implementation of IBSE is, in the research sense, problematic. The SCeTGo material, along with anything else, can be used in ways it was not intended. It is possible that material based on highly transmissive pedagogy can be incorporated in inquiry-based learning and on the other hand it is entirely possible to use SCeTGo miniatures in a very transmissive way. It is entirely possible to use the apparatus under strict teacher control and for the teacher to tell the students what they are seeing.

Even where teachers are following syllabi that are explicitly inquiry-based such as the curricula published by the Nuffield Trust in the UK in the 1960's and 70's Atkinson and Delamont [19] demonstrated a degree of stage management:

"This form of school science proceeds on the tacit assumption that the pupils are engaged in the discovery of phenomena which are already well-known, and which the teacher has already set up as the end point of their endeavors. In other words, what is at stake in teaching situations of this sort is not so much that the relevant conclusions should remain undisclosed, but rather, that they should appear in the appropriate manner and at the appropriate time." ([19], p. 103)

They describe replication of the scientific discovery requiring the stage-managed revelation of knowledge by the teacher. They report that the work of stage management of science lessons requires practical skills for immediately dealing with contingencies for all practical matters. They also point out that such practical skills are required of students as well as teachers. That is, the teacher and students should act as if the answer to what they are inquiring into were not already established. Both students and teachers find these situations difficult to handle as there is a tension between "actually making a scientific inquiry" and, on the contrary, trying to affirm the nature of the science as "need to understand what they are going to be examined on". The management involved in sustaining the demonstration's reality depends upon the participants acting as if the answer to the puzzle were not already established or as if the phenomena under consideration were not to be treated as too problematic. They suggest that students play games of "guess what answer the teacher is looking for" and in turn teachers carefully manipulate the classroom conversations to get the predetermined answer they expect. As the title of the paper suggests, in dialogues that are supposedly inquiry-based, the teacher steers to conversation that might cover up mistakes in readings or observation so that the students get what would be the content of a lecture on the same topic. This is hardly IBSE.

Clearly there are issues that need further research in IBSE in general but for SCeTGo we need to know how teachers as engaging (or not) in IBSE with our miniatures, their language patterns, the way that they pose questions, and the ways the situation is established for students.

5.3. The SCeTGo Experience 3: Learning with Augmented Reality

Aside from the inquiry-based approach there are also questions we must ask about learning specifically from our augmented reality miniatures that apply to the direct experience. The miniatures are simulations that exist as simulated science apparatus or real world objects overlaid with a simulation of otherwise invisible information. The exception is the mini-double cone, which is neither a simulation nor does the overlay show the invisible. In this case the AR provides measurement of angles and a calculator.

The research questions we need to address are:

- Do students effectively learn from the simulation (when used with ISBE methodology)?
- How does the student learn through simulation?
- Does the augmentation support understanding of the phenomena presented?
- Do students understand what the augmentation is actually representing? (Or does it compound confusion?)
- Are there key heuristics we can derive from our practice that inform the design of future AR simulations?

Early research on learning through computer simulations suggests a good correlation between inquiry-based learning and learning through simulation. Macdonald et al. [20] and Kemmis et al., [21] suggest a method of learning with simulation that they describe as revelatory. The idea is that a simulation is a model of a phenomenon and through interacting on the simulation the model becomes gradually revealed to the student. This is an experimental non-random trial and error approach in which students refine their understanding and become more effective in predicting the outcomes of the actions they take. It requires the simulation to provide direct feedback of the effect of the student's action on the simulation that is a direct result from the student's action.

The richness and effectiveness of our miniatures will be determined by the accuracy of the simulation and the quality of feedback the student gets. The AR overlay is the feedback, although we have had requests from teachers who have interacted with the miniatures, especially the double slit experiment, to have more quantifiable/numeric aspects such as making measurements based on physical changes in the miniature (such as changing the spacing between slits).

In most cases manipulation of the miniature results in a direct effect on the visual overlay with good accuracy. The student can do most of the testing to the limit of the simulation, which supports revelatory learning. The key question is about the effectiveness of the feedback that is provided by the overlay and the student's ability to understand it. People watched many apples fall from trees before gravity was formulated as a hypothesis. Many baths were taken before the Eureka moment. We are seeking new ways to trigger inquiring minds to trigger insight of what is happening in front of our eyes.

We are adding complexity to a situation in the belief that the extra information leads to a better understanding and to a scenario where learners can formulate and test hypotheses. In the case of IBSE we believe that we are providing significant extra clues that we will help the learner formulate a theory through a scaffolding of the observation.

According to the information theory [22], from the point of view of learning about certain phenomena, the learner should observe change and reflect on it in order to understand what is happening. Bateson [22] defined information as "a difference which makes a difference." (i.e. it is within the difference where the main information for the learner is). The challenge is to design the right and significant differences within the overlay. It is not enough to draw lines to show the air over an aeroplane wing. The lines need to clearly show a difference. The difference really needs to be communicated to the student. Moreover the really important factor is that the student has to recognise the difference and know that the difference is salient. Newton knew this for apples. The rest of the world didn't. This is a significant challenge for the pedagogy of AR.

In order to make AR to be of value, the overlay has to be strong in showing the "difference", otherwise we are just contributing to confusion. Indeed, AR should be amplifying the difference. The pedagogy of AR (which we are pioneering) needs to be clear in delivering the advantage. This advantage comes not just from showing what cannot be seen, but making sure that when the invisible is made visible it adds value and not confusion.

We have devised some tests that ask the students questions of their understanding of the science and their understanding of the AR. These tests not only ask questions about the phenomenon under study but also the (augmented) overlay. They attempt to address misconceptions that the overlays may engender, for example the true/false multiple-choice question stems:

all electrons are blue, or,
the blue lines represent the peaks of waves,
the darker colours represent higher frequencies

These tests have yet to be validated and implemented. However, they are an essential part of understanding what a student makes of an inquiry using miniatures. If we get negative results on a student's understanding of the representation then clearly the simulation is more confusing than supportive.

In our final analysis the challenges for the scenario designers are:

1. Adding AR should do something that is difficult to do without AR.
2. Adding things you cannot see/hear - it may be measurements, vectors/scalars, particles, waves, etc.
3. Teachers should not have to spend more time explaining the AR overlay than they would on the phenomenon itself.
4. The AR should be truly explanatory or preferably the AR contributes to an investigation of a phenomenon, which is important for IBSE.
5. Teachers should not have to tell students what the AR is showing and apologise for where it is confusing. In general, misconceptions could be expected but such misconceptions should not be a result of poor design or implementation of the AR.
6. AR should amplify the differences that make the phenomenon understandable.
7. AR experiments should be flexible enough to allow usage in different scenarios and in different moments of the lesson/learning process

We describe some of the ways that SCeTGo could do this in the tables in the Appendix.

7. Conclusion

The project has developed some interesting classroom apparatus for science education. Our findings are that teachers are interested, looking forward for new improved developments. In a widespread pilot we would like to further research:

a) the factors that make ICT-based resources more easily incorporated into teacher's planning of educational experiences;
b) the ways in which AR/ICT resources encourage teachers to adopt approaches on inquiry-based and collaborative learning, showing its advantages;
c) ways in which AR provides well-interpreted additional information that enables students to better understand scientific phenomena.

8. Acknowledgements

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Appendix

Mini-wing (wing dynamics)

Real world difference[1]	**Physics difference**[2]	**SCeTGo design**	**SCeTGo difference** *These are design considerations in implementation*	**Student perception specific to the AR implementation**
the plane goes up i.e. flies	Air pressure above the wing is less than below the wing producing upthrust.	We show changes in the direction of the flow of air by representing airflow as lines. We clearly need to show a difference in speed of airflow and that needs strong exaggeration. As the fan moves towards the wing the airflow increases. Arrows whose length varies and direction changes show drag and uplift .	Lengths of arrows change Direction of lines change Frequency of arrows on flow lines increase.	The student clearly has to be aware of what it is the overlay is actually showing, etc. and if it is showing a variable (like velocity of airflow) then that has to be emphasised.

[1] *Real World Difference is what the everyday observer perceives without asking scientific questions.*

[2] *Physics Difference is the explanation that a good science teacher would use to explain a phenomenon.*

Mini-cooler and heater (kinetic theory of gases)

Real world difference	Physics difference	SCeTGo design	SCeTGo difference *These are design considerations in implementation*	Student perception specific to the AR implementation
Hot and cold are subjective appreciations of temperature. We experience the air as having different temperatures.	Temperature of a gas is a function of the kinetic energy of the gas molecules. The higher the velocity of the molecule the higher the temperature. This energy is a function of the square of the velocity. $pV = NkT$	We make visible a fixed number of spheres that represent molecules within a specific volume. We measure temperature in three environments. The speed of the molecules changes in the three environments. This is reflected on the on-screen temperature and graph.	Perceiving the changes in speed is crucial. Should there be a countable number of molecules? How we have students appreciate the control of variables?	Students have to appreciate that the speed of the spheres represents the speed of particles. Students have to recognize that at different temperatures have different speeds. Certain aspects of the phenomenon, mainly relating to the density of gas at different temperatures, may cause confusion.

Mini-double slit (quantum mechanics)

Real world difference	Physics difference	SCeTGo design	SCeTGo difference *These are design considerations in implementation*	Student perception specific to the AR implementation
When light (or any electromagnetic source) or an electron source is projected onto a screen through double slits an interference pattern is detected on a detection screen. This phenomenon seems to hold when describing light or electrons as waves - emulating what is observed when water or sound waves are subjected to a similar set up. However it obviously holds true even if we believe light or electrons to be particles. Except, if we have a detector to detect particles, the phenomenon does not occur, i.e. once we decide that radiation or electrons behave as particles and detect them as such the phenomenon is not observed.	The phenomenon is described by the equation: $\frac{n\lambda}{d} = \frac{x}{L} \Leftrightarrow n\lambda = \frac{xd}{L}$ where λ is the wavelength of the light, d is the separation of the slits, the distance between A and B in the diagram to the right n is the order of maximum observed (central maximum is n = 0), x is the distance between the bands of light and the central maximum (also called fringe distance), and L is the distance from the slits to the screen centre point.	We provide a virtual gun firing particles, waves or electrons/ photons through one or two slits onto a screen. The distance of the slits from the gun can be varied. The pattern appearing on the screen is shown. There are three different kinds of animation overlays. The overlay's result will vary dependent of the spacing of the slits used. This will change the pattern on the screen.	As Waves, the overlay will replicate wave tanks and wave tank interference patterns. As particles, as discrete blobs are fired at the slits. These will build up interference patterns with distribution of "blob hits". In electron/ photon mode particles are fired but an interference pattern appears on the screen.	The main limitation in perception is that ripples/waves are normally viewed from above. To observe the particle behaviour we would need to view from a different angle. The animation of particles gives an idea of time lapse and the pattern builds up. For waves there is a continuous show of the interference phenomena (as happens in real life).

Mini-fire truck (the Doppler effect)

Real world difference	Physics difference	SCeTGo design	SCeTGo difference *These are design considerations in implementation*	Student perception specific to the AR implementation
As a fire engine approaches, the pitch of the notes of the siren seems higher than it would be for a static vehicle. As it moves away it gets less. This is compounded by changes in volume one might expect. However the change in note is perceived as the vehicle passes. A phenomenon is also noticed when the source is stationary and the observer is moving; and any combination of movements of the two. In the real world, but not experienced by people or observable in a school or museum, are shifts in the light spectrum in large astronomical objects within an expanding universe.	When an object that is a source of a wave and an observer are moving relative to each other there is a change in wavelength of the wave is perceived by the observer. With sound this appears as change in pitch; in light, at astronomical speeds, this appears as a change in the spectrum.	We have a model fire engine as the source of waves and a model sound detector/ observer. In a static situation wave propagation is perceived as concentric circles of different intensity of red – these may be explained as the wave fronts/ peaks. When the source moves the wave fronts appear to be much closer together in the direction of travel. This makes the circles appear as ellipses.	There are two and possibly three significant differences with the sound wave experiment; changes in pitch, the change in the shapes of the patterns and colours of the propagation of sound changing the apparent wave propagation in the direction of travel. We might consider changing the volume.	The crucial understanding comes from knowing the way we are representing the propagation and speed of sound waves, i.e. the slower sound waves are moving the closer they are. The important difference for the student to observe is simultaneously realising that the change in frequency of the sound source and the apparent asymmetric propagation of the sound “circles”. This is not so apparent when the observer moves. This is difficult to represent.

Combining Science Center To Go´s miniature exhibits and Open Science Resources´ inquiry-based learning pathway

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Abstract

This paper shows as an example, how different pedagogical projects are possible and worth to combine. Open Science Resources and SCeTGo´s are both funded by European Union.

Keywords

Inquiry-based learning, Open Science Resources, Science Center To Go

1. Introduction

In this paper we present an educational scenario that follows the inquiry-based science education methodology and makes use of the online scenario template that is offered to users of the Open Science Resources portal.

2. Pedagogical background

Inquiry-based learning describes a range of philosophical, curricular and pedagogical approaches to teaching.

Inquiry-based learning is an instructional method developed during the discovery learning movement of the 1960s. It was developed in response to a perceived failure of more traditional forms of instruction, where students were required simply to memorize fact laden instructional materials (Bruner, 1961). Inquiry learning is a form of active learning, where progress is assessed by how well students develop experimental and analytical skills rather than how much knowledge they possess.

Now an important aspect of inquiry-based science is the use of open learning. Open learning is when there is no prescribed target or result which students have to achieve. In many conventional traditional science experiments, students are told what the outcome of an experiment will be, or is expected to be, and the student is simply expected to ‘confirm’ this.

In open teaching, on the other hand, the students are either left to discover for themselves what the result of the experiment is, or the teacher guides them to the desired learning goal but without making it explicit what this is. Open teaching is an important but difficult skill for teachers to acquire.

Open learning has many benefits. It means students do not simply perform experiments in a routine like fashion, but actually think about the results they collect and what they mean. With traditional non-open lessons there is a tendency for students to say that the experiment 'went wrong' when they collect results contrary to what they are told to expect. In open lessons there are no wrong results, and students have to evaluate the strengths and weaknesses of the results they collect themselves and decide their value. Because the path taken to a desired learning target is uncertain, open lessons are more dynamic and less predictable than traditional lessons.

Open learning has been developed by a number of science educators including the American John Dewey and the German Martin Wagenschein. Wagenschein's ideas particularly complement both open learning and inquiry teaching. He emphasized that students should not be taught bald facts, but should be made to understand and explain what they are learning. His most famous example of this was when he asked physics students to tell him what the speed of a falling object was. Nearly all students would produce an equation. But no students could explain what this equation meant. Wagenschien used this example to show the importance of understanding over knowledge.

Inquiry-based learning has been of great influence in science education, where it is known as Inquiry-based science, especially since the publication of the U.S. National Science Educational Standards in 1996. Since this publication some educators have advocated a return to more traditional methods of teaching and assessment. Others feel inquiry is important in teaching students to research and learning (e.g., see Constructivism (learning theory)).

Scientists use their background knowledge of principles, concepts and theories, along with the science process skills to construct new explanations to allow them to understand the natural world. This is known as "science inquiry".[1]

The National Science Education Standards call for students to do inquiry, and to know about inquiry. When students do inquiry, they use the same ideas as scientists do when they are conducting research. Students become 'mini-scientists.'

When students are learning about inquiry, they should become familiar with the processes used by scientists, and the new knowledge that results. Inquiry is a natural introduction to the branch of epistemology known as the Nature of Science, which deals with the characteristics of scientific knowledge.

The National Science Education Standards were often misunderstood with regard to inquiry-based learning. As a result, the National Research Council put out a second volume, entitled 'Inquiry and the National Science Education Standards' in 2000.

Heather Banchi and Randy Bell (2008) suggest that there are four levels of inquiry-based learning in science education: confirmation inquiry, structured inquiry, guided inquiry and open inquiry. With confirmation inquiry, students are provided with the question and procedure (method), and the results are known in advance. Confirmation inquiry is useful when a teacher's goal is to reinforce a previously introduced idea; to introduce students to the experience of conducting investigations; or to have students practice a specific inquiry skill, such as collecting and recording data.

In structured inquiry, the question and procedure are still provided by the teacher; however, students generate an explanation supported by the evidence they have collected. In guided inquiry, the teacher provides students with only the research question, and students design the procedure (method) to test their question and the resulting explanations. Because this kind of inquiry is more involved than structured inquiry, it is most successful when students have had numerous opportunities to learn and practice different ways to plan experiments and record data.

At the fourth and highest level of inquiry, open inquiry, students have the purest opportunities to act like scientists, deriving questions, designing and carrying out investigations, and communicating their results. This level requires the most scientific reasoning and greatest cognitive demand from students.

The philosophy of inquiry based learning finds its antecedents in the work of Piaget, Dewey, Vygotsky, and Freire among others [1,2].

Inquiry learning emphasizes constructivist ideas of learning. Knowledge is built in a stepwise fashion. Learning proceeds best in group situations.

The teacher does not begin with a statement, but with a question. Posing questions for students to solve is a more effective method of instruction in many areas. This allows the students to search for information and learn on their own with the teacher's guidance.

The topic, problem to be studied, and methods used to answer this problem are determined by the student and not the teacher (this is an example of the 3rd level of the Herron Scale)

The above comments represent a classroom that is fully committed to inquiry, to the greatest extent possible. However, it is not necessary to take an all-or-nothing approach to inquiry-based teaching methods.

In the 1960s, Schwab called for inquiry to be divided into four distinct levels. This was later formalized by Marshal Herron in 1971 [3], who developed the Herron Scale to evaluate the amount of inquiry within a particular lab exercise. Since then, there have been a number of revisions proposed, but the consensus in the science education community is that there is a spectrum of inquiry-based teaching methods available.

Students develop a method to find which antacid tablets are the best at neutralizing acids.

Students learn about inertia and movement by studying the effects of rolling of marbles on different surfaces.

Students work in groups to build bridges to hold marble weights. By doing so they discover how to build strong bridges.

Inquiry based learning is a way of assuring students become more actively involved in what they are learning, particularly in the content area of Science.

A special case of inquiry learning is problem-based learning (PBL). Students are assigned to teams and provided with an ill-defined problem. Teams must organize themselves, define objectives, assign responsibilities, conduct research, analyze results, and present conclusions. The problems are purposely "ill-defined," causing team members to work collaboratively to define specific issues, problems, and objectives. Such tasks mimic the problem-solving skills that professionals engage in, whether repairing automobiles, or treating cancer patients. Problem-based learning employs open-ended questions that are not limited to a single correct answer. The questions elicit diverse ideas and opinions and require students to work as a group. Problem-based learning naturally integrates various fields of study as students search beyond the traditional curricular boundaries to develop solutions.

The Hands-On Universe (HOU) project is an educational program that enables students to investigate the Universe while applying tools and concepts from science, math, and technology. Using the Internet, HOU participants around the world request observations from an automated telescope, download images from a large image archive, and analyze them with the aid of user-friendly image processing software. The HOU pedagogical resources are typical tools inspired from Inquiry-based science education (IBSE) [4].

3. OSR-project and OSR-portal

OPEN SCIENCE RESOURCES (OSR) is a collaborative project co-funded by the European Commission under the eContentplus programme.

The project started in June 2009 and will continue for 36 months.

The aim of the OSR project [5] is to create a shared repository of scientific digital objects - currently dispersed in European science museums and science centres - to make them more widely and coherently available, searchable and usable in the context of formal and informal learning situations.

The OSR portal [6] contains educational material in the form of educational content (images of exhibits and scientific instruments, videos, animations, exercises, graphs, links) and of educational pathways (structured and open learning activities organized according the inquiry based pedagogical model). Users can search for the educational materials in the “Explore OSR” section or to upload their own materials to the OSR Repository, using the “Share your Content” section..

The initial OSR Educational Pathways (demonstrators) were developed from teachers and museum educators who are involved in the project, following specific teaching approaches. The educational pathways are a combination of scenarios of use that interconnect content available in different museums and science centres enriched with content from different sources along with content developed by visitors themselves. Each pathway includes pre-visit activities (e.g. on the web), visit activities (during conventional or virtual tours) and post-visit activities (in the web environment). The OSR approach introduces the educational potential of the science centres and museums.

4. Combining SCeTGo´s miniature exhibits and OSR´s inquiry-based learning pathway[6]

The SCeTGo project [7] integrates the AR technology in science teaching both in formal & informal educational environments. The main aim is to offer to users an alternative approach in learning science through the visualisation of invisible physical parameters. OSR-portal offers an ideal framework to use inquiry-based learning procedure as a learning tool with SCeTGo´s miniature exhibits. Teacher can easily combine the best properties of both to the most effective learning experience.

5. An example: Mini-cooler & heater

Mini-cooler & heater (kinetic theory of gases) Boltzmann’s constant, also called the Boltzmann constant and symbolized k or k B , defines the relation between absolute temperature and the kinetic energy contained in each molecule of an ideal gas . This constant derives its name from the Austrian physicist Ludwig Boltzmann (1844-1906), and is equal to the ratio of the gas constant to the Avogadro constant. In general, the energy in a gas molecule is directly proportional to the absolute temperature. As the temperature increases, the kinetic energy per molecule increases. As a gas is heated, its molecules move more rapidly. This produces increased pressure if the gas is confined in a space of constant volume, or increased volume if the pressure remains constant.

In this miniature the movement of molecules is represented on the screen, when molecules are ice-cold, room temperature and heated . This can be used in teaching about the behaviour of molecules in general, and the Boltzmann constant in particular.

5.1. Mini-cooler & heater OSR pathway

The students make a short study of heath and molecular velocities using Science Center To Go Mini Heater et Cooler exhibit. The demonstration of the experiment is based on advanced visualization techniques.

5.1.1. Introduction

Original Title: Mini Heater et Cooler

Classification: Scientific communication, Prediction compared to results, Temperature and heat, Velocity, Thermodynamics, Kinetic energy

Age Range: 15-18

Context: school-connected

Learning Time: more than 2 hours

Guidance for preparation

Description: Students will perform some experiments about gases in order to learn about the behaviour of gases both in macro and micro level. The demonstration of the experiment is based on advanced visualization techniques.

The early gas laws were developed at the end of the 18th century, when scientists began to realize that relationships between the pressure, volume and temperature of a sample of gas could be obtained which would hold for all gases. Gases behave in a similar way over a wide variety of conditions because to a good approximation they all have molecules which are widely spaced, and nowadays the equation of state for an ideal gas is derived from kinetic theory. The earlier gas laws are now considered as special cases of the ideal gas equation, with one or more of the variables held

Experimental Set-Up

The demonstration/experimentation includes two main experimental set-ups. The first includes the experimental

- A cylinder with piston. Mediacal injection syringe is good.
- Hot and cold water, ice cubes are giid to make the water cold.
- Science Center to Go AR Software
- Science Centre to Go Mini Cooler & Heater Exhibit
- PC and projector
- Access to the Internet

5.1.2. Pre Visit

5.1.2.1. Provoke curiosity

Teacher makes with students a little investigation into the gas laws.

The equipment needed are

- A cylinder with piston. Mediacal injection syringe is good.
- Hot and cold water, ice cubes are giid to make the water cold.

The investigation is qualitative by nature. The purpose of it is just demonstrate, that air and other gases tend to expand when heating and contract when cooling.

The question that should rise from observations is: What happens in the molecule level in the gas. Why hot gas expands and cold contracts?

5.1.2.2. Define questions from current knowledge

The observation is: The volume increases, when the temperature rises and vice versa the volume degreases, the temperature falls. What does this mean in a molecule level?

- The molecules of the gas has similar thermal expanding as solid objects. The size of the molecules changes when the temperature changes?
- The molecules need more space, when the gas is heated.
- the essential question is: “Is it possible to solve the mechanism of gases thermal expansion in molecule level using macro level observations?”
- Students will discuss about this in small groups and every group will give one answer, with justifications.

5.1.2.3. Propose preliminary explanations or hypotheses of gas laws

Students will think, why the explanation of the thermal expansion of the gases is better using the movement of gas molecules than using the thermal expansion of the gas molecules itselves.

- Gas is so thin prepared to the solids abd liquides, that the size of the gas molecules must be irrelevant.

5.1.2.4. Plan and conduct simple investigation

Students will make not only qualitative but also quantative investigation into the relationship between the temperature and volume of a gas. The equipment are still the same + thermometer.

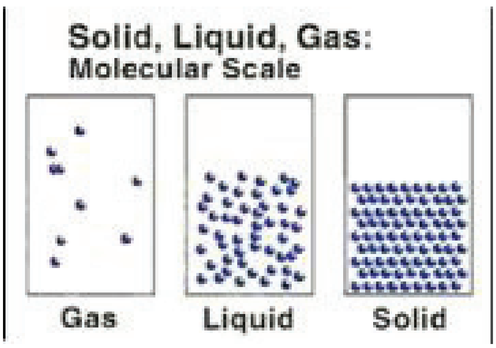
Students measure the temperature of water using 4-5 different temperature in a range 0 - 100 degrees Celsius and the volume of the air in the syringe. Then they will draw a plot from the data. The results using this kind of simple equipment are rather rough, but it is easy to imagine, the the relationship is linear and the plot is a straight line.

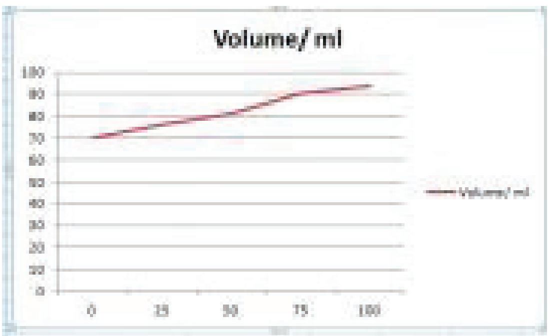
Next step is to find the mathematical relationship between temperature and volume. This is basic mathematics in the second grade. The equation of the straight line in this case is y = 0,25*x - 270.

Very obvious question is: “What is the temperature, if volume is 0 ml?”

Answer is, that temperature is -270 Celsius degrees. It has to be the lowest temperature, because the volume cannot be negative.

Finding the absolute zero point is better make with a proper plot blogger program. Excel is not good for this purpose.





5.1.3. Visit

5.1.3.1. Gather evidence from observation

The teacher is using the Mini Cooler & Heater exhibit, following the guidelines that are provided with the Tool-Box.

The teacher shows, how the system works. Then the students start to study. The main purpose is to solve, what kind relationship is between the gas molecules and temperature of the gas.

There are some questions, which the Mini Cooler & Heater exhibit gives answers to, but many question might remain unanswered. Like

What kind mathematical model is between temperature and gas molecules?

Are the velocities of the gas molecules uniform or do they have some kind distribution?

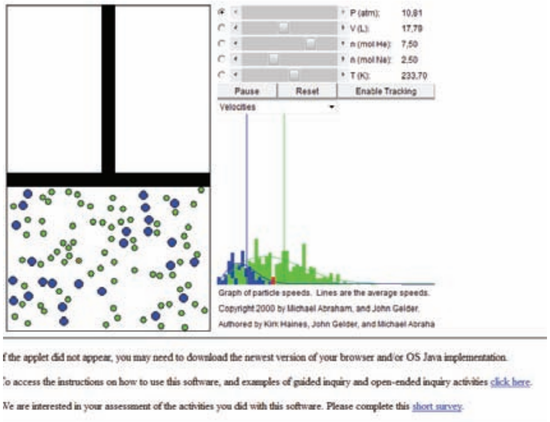
Do different gas molecules behave different? For instance oxygen and nitrogen molecules, the main elements of the air.

Do atoms and molecules as a gas state behave different ways? For instance noble gases vs. bi-atomic gases or tri-atomic non symmetrical gases like water vapour.

5.1.3.2. Explanation based on evidence

Good way to explain the relationship between temperature and gas molecules is to use proper interactive teaching program.

Some of them are more qualitative, some quantative.



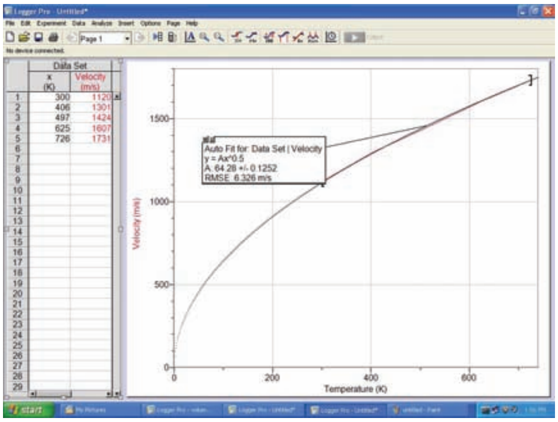
5.1.3.3. Consider other explanations

It is important, that the students understand, that temperature is a macro property of matter and the velocity of molecules is a micro property of the elements of the matter. In gases they are linked together by an equation [1/2*m*v^2=3/2*k*T]

The students use this program Moleculal Speed Calculation to find how the velocity of gas molecules depends on temperature.

Students can use the ready Excel-sheet, which plots the v(T) graph. Note, that temperature must be in kelvin degrees.

Many data-collection and analysis application like Logger Pro 3 are also very handy for this purpose.



5.1.4. Post Visit

5.1.4.1. Communicate explanation

The students should report on the realized activities. The will need to prepare a report that includes the rational of the experiment, the initial design of the experimentation, the experimental set-up, the realization of the process, the analysis of the findings and a detailed discussion on the results. Students could work in groups, prepare their reports and then present them in the classroom.

Teacher should encourage the students to use photos and videos as research tools. The modern cell phones have many useful properties, not only photo and video camera.

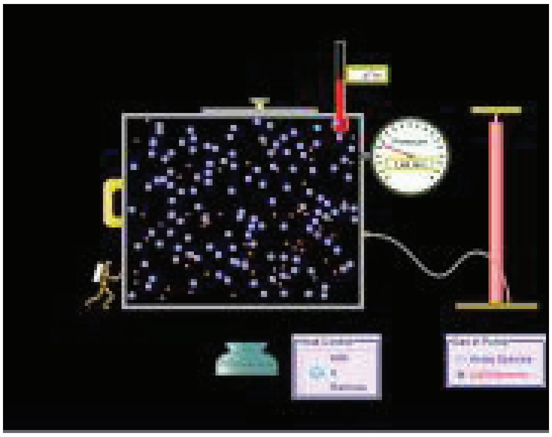
5.1.4.2. Follow-up activities and materials

Good links and tests

Very nice interactive animation about gas laws [8].

Interactive animation about states of matter [9].

Another interactive animation about gas laws. The velocity distribution depending on temperature is very clearly to see [10].



5.1.4.3. Test

Choose one

Kinetic theory of gas atoms

1. Gravity has influence to the movement of gas atoms
   a. slightly
   b. not at all
   c. heavy

2. Temperature of the gas measured in kelvins is
   a. proportional to average speed of gas atoms
   b. proportional square of average speed of gas atoms
   c. inverse proportional square of average speed of gas atoms
3. The velocities of gas atoms are
   a. all the same
   b. they varies
   c. they are quantified
4. The square of average speed of gas atoms and the average of the square of velocities
   a. are the same
   b. differs
5. The average kinetic energy of the light atoms compared to the kinetic energy of the heavy atoms in a gas with the same temperature
   a. is the same
   b. is greater
   c. is smaller
6. The average speed of gas atoms below 0 K temperature
   a. is negative
   b. is zero
   c. is infinite
   d. is c (speed of light)
   e. is impossible to say, because 0 K is the lowest possible temperature
7. The highest possible temperature is reached
   a. when the speed of the gas atoms is speed of light
   b. when the speed of the gas atoms turns negative
8. The temperature measured of the air in Celsius degrees is proportional
   a. speed of the gas molecules
   b. square of the velocities of gas molecules
   c. Temperature of the air has not so ever proportional relationship to the velocities of gas molecules
9. Kinetic gas theory is valid only for
   a. ideal gas
   b. one atomic gases
   c. molecular gases
10. One air molecules collide to the other molecules in NTP circumstances (give the right approximation)
   a. one times in a second
   b. thousand times in one second
   c. billion times in one second

6.Conclusions

Combining SCeTGo´s miniature exhibits and OSR´s inquiry-based learning pathway is a fine example, how these kind projects produce together extra value.

The method is used already by some test groups and the results seem very promising.

7. References (and Notes)

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Evaluation of a portable and interactive augmented reality learning system by teachers and students

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Abstract

This study investigates the role of teachers' and students' acceptance of a learning approach within the Science Center To Go system. Science Center To Go specifically makes miniaturized Augmented Reality exhibits available out of science centers. In this paper we focus on a qualitative teacher- and student-centered evaluation of the technical acceptance and pedagogical effectiveness of the system. The study indicates that acceptance is high in general and that pedagogical effectiveness is very positive rated. It also shows that a meaningful evaluation of such a system in a real school environment heavily demands prototypes with extraordinary usability and robustness, to be fully reliable for teachers.

Keywords

Mixed and Augmented Reality, Hands on, Technology acceptance, Technology-enhanced learning, Usability evaluation

1. Introduction

In contrast to Virtual Environments that completely immerse users into a virtual world, Augmented Reality (AR) combines the real world with artificial, computer generated elements. The mixture of real and virtual information, as a new kind of user experience conducted in a science centre, has been shown to positively influence students' intrinsic motivation, as well as cognitive learning, especially of low achieving students. It thereby can help to maintain pedagogical effectiveness [1-4].

However, the implementation of AR in school environments as a new way of learning was so far only realized and evaluated in very few cases [5, 6]. The Science Center To Go (SCeTGo) project is offering an innovative approach to the needs of teacher instruction in the classroom, by adapting an existing AR system for science centres and other informal learning settings [3, 7].

In the framework of SCeTGo a series of miniature exhibits were developed, illustrating various physical phenomena which enable learners to visualize the invisible (e.g. electric or magnetic fields, molecular movements) through AR technology. In this manner learners have the chance to control conditions in order to uncover and visualize physical phenomena. In so doing they participate in an active learning form that enables students to investigate physical phenomena instead of simply memorizing facts. Pupils enhance their experimental and analytical skills together with an appropriation of knowledge with regard to natural sciences.

In order to improve quality of the miniature exhibits, animations of physical processes in the classroom are accomplished by pedagogical scenarios. A detailed description is presented in the current issue [15]. Scenarios are tangential to the curriculum. An inquiry-based learning scenario is performed as follows:

- Phase 1: Question Eliciting Activities
- Phase 2: Active Investigation
- Phase 3: Creation/ Formation
- Phase 4: Discussion
- Phase 5: Reflection

This way the SCeTGo setup assures an innovative inquiry-based learning approach that is tailored to students` needs and implements not only “hands-on”, but also ‘minds-on’ experiments. Additionally, it allows teachers a successful application within school curricula without the need to a time consuming preparation of teaching material.

Bringing AR into classrooms seems to be a promising approach in consideration of the referred advantages. However, making AR computer-mediated learning technology attractive to teachers needs to consider teachers requirements: Teachers still act as key players in the use and acceptance of any new educational technology and there remains an enormous gap between developing AR technologies and its implementation in school [4]. Therefore this study is one of the few attempts to investigate the role of teachers’ and students` acceptance of AR in school environments. Both user groups (teachers and students) have their own requirement and operate with a new AR technology in a different way. Which conditions have to be considered that AR has an impact on education in long term?

The main objectives of the present study include a validation of (1) the pedagogical approach and educational value as well as of (2) technical issues of the SCeTGo system.

In the following, we will present the suitcase and its first evaluation results. After describing the SCeTGo suitcase in section 2, we will illustrate the evaluation methodology and results in section 3 and 4. Finally we will discuss our findings in section 5.

2. The Suitcase

The Science Center To Go (SCeTGo) is based on work of the consecutive projects CONNECT [7] and EXPLOAR [10, 11].

The suitcase stores all necessary elements for the existing five exhibits. Also included in the suitcase is a laptop with a touch screen, a webcam and a little stand. The webcam is placed on the stand and connected to the computer. On startup the computer directly starts into the SCeTGo main screen; ready to set up one of the exhibits in front of the webcam. The webcam stream is displayed on the computer screen and augmented with additional content. In the following we will briefly describe the five exhibits currently included in the suitcase. A more detailed description may be found in [11]. Further information to pedagogical intentions pursued by the miniatures is given in [15] [17].

2.1 The Mini Wing Experiment

The Mini Wing consists of a small box that stores the model of an airplane wing. The wing is about 5.5 cm long, 3 cm wide and 1.5 cm high.

The wing is mounted on an axle to change its angle of attack. A USB powered fan generates an air stream. The air stream is visualized in the AR view as shown in Figure 1.

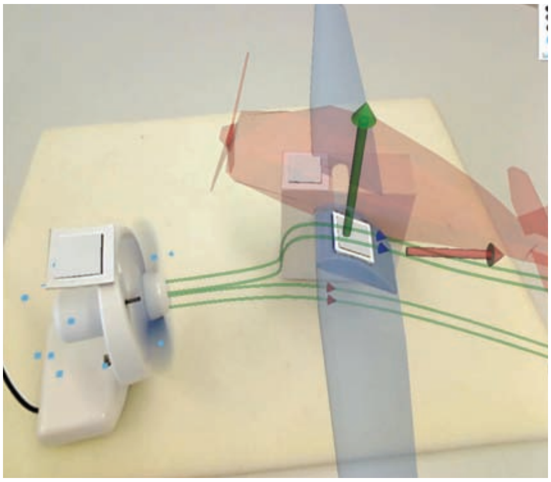

Figure 1. The Mini Wing exhibit augmented through an airflow coming from a USB powered fan. Two arrows are displaying the lift and drag, the movement of air molecules is displayed at the fan.

Forces of lift and drag are indicated through arrows at the wing model. The virtual content of the augmented view is instantly adapted for new angles of attack. Learners might change the airstream by changing the position of the fan as well as trying out differently shaped wing models.

2.2 The Doppler Experiment

The Doppler Experiment consists of a sound emitting fire truck and a virtual microphone representing a listener. The sound of a fire truck siren together with a visualization of its wave propagation is instantly simulated in Augmented Reality (AR). The simulation is chronologically scaled down by a factor of 500. Users are able to move both, the listener and the sound fire truck.

2.3 The Double Slit Experiment

Learners are invited to test the double slit with a virtual cannon shooting big particles or electrons at a slit. The cannon might also be replaced by a source emitting waves with a certain frequency. In particle mode a virtual cannon fires little “cannon balls” at the slit screen. After numerous balls a pattern analogous to a slit appears at the projection plane (compare Figure 2).

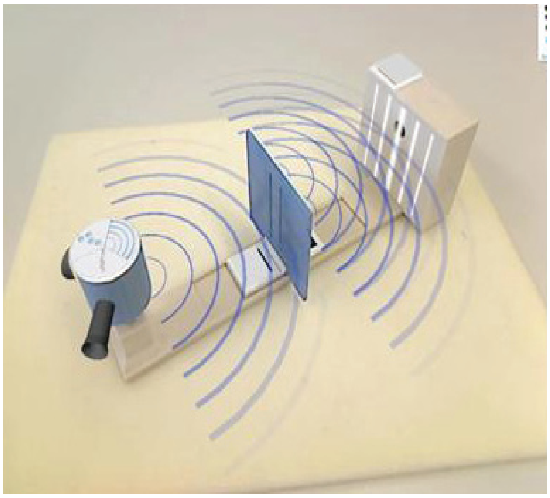

Figure 2. The double slit setup consisting of a floor board (dark), the slit board in the foreground, a box as a projection plane, and a virtual cannon

Users are able to move the slit board, and switch between single and double slit.

2.4 The Double Cone Experiment

The double cone miniature consists of two rails of 12 cm length each. The rails are jointly connected on one side; on the other side each rail rests on a ramp. The ramps provide an inclination of 1.5 cm by 3 cm. Additionally four rolling objects are available to be put on the rails. Three of the rollers are double cones and one is a cylinder. The opening angle measured alongside the double cones differs between 15, 30 and 45 degrees.

Users may change the slope or opening angle of the rails. The AR system tracks the setup and displays the formula describing the current constellation, directly when users make changes.

2.5 The Boltzmann Experiment

The Boltzmann Experiment contains a USB powered freezer, a thermometer, and a USB powered heating surface. Learners are able to feel and measure the temperature at different areas of their setup. Additionally, molecule movement is visualized at the tip of the thermometer. On the AR screen users might observe that molecules in areas of a high energy, near the heating surface, move faster than molecules around areas of low energy, e.g. inside the refrigerator.

3. Evaluation – Material and Methods

During the implementation phase of the SCeTGo system (07/2010 -11/2011) miniatures were introduced to teachers and students.

SCeTGo was presented to 72 Finish pre-service science teachers and 27 Romanian in- service science teachers at schools within a professional development framework. During such courses, participants were offered information about the project, the Augmented Reality (AR) technology and its application in the classrooms.

Learning scenarios were presented and teachers were given an introduction about technological aspects, including an explanation about the handling of the tool. Thereby, teachers could interact with all exhibits and AR features that were developed in the framework of the SCeTGo system.

Scenarios, together with the corresponding miniatures have been shown to be adequate for pupils aged between 15 and 18 years [15] [17].

As part of students' evaluation learning scenarios and miniatures were presented to a total of 512 Romanian pupils aged between 14 and 18 years. Scenarios, together with the corresponding miniatures were divided evenly to appropriate age groups. After the successful implementation workshop leaders consulted teachers as well as students, willing to be interviewed.

Altogether 29 Finnish pre-service science teachers (gender: ♀ 22, ♂ 7; age: Ø 26.8, range: 19-51 years) and 19 Romanian in- service ones (gender: ♀ 16, ♂ 3; age: Ø 45.8 range: 33-55 years) teaching in inferior and upper secondary school, were asked about their attitudes towards SCeTGo and its carrying out in school.

Additionally, individual interviews have been conducted with 32 Romanian students (gender: ♀ 23, ♂ 9; age: Ø 15.4, range: 14-17 years).

Two categories of questions with regard to teachers' and students` motivation to use the system in consideration of usability and pedagogical aspects were addressed. Interviews had an average duration of 20 minutes. To guarantee homogeneity of data, interviewers followed general principles according to descriptions of Lamnek [12]. All questions were adjusted in an open form and interviews were incorporated in a trustful situation.

Interviews were analysed following Mayring`s qualitative content analysis [13]. A category was formed, if not less than two interviewees referred to the same aspect.

4. Evaluation – Results

We present a summarising content analysis, integrating the results of individual interviews that have been conducted with the sample reported above. Selected questions considering (1) pedagogical effectiveness and (2) technical acceptance of the system are presented.

4.1 Students` Evaluation

All students asked if they were satisfied with the lesson answered in the affirmative.

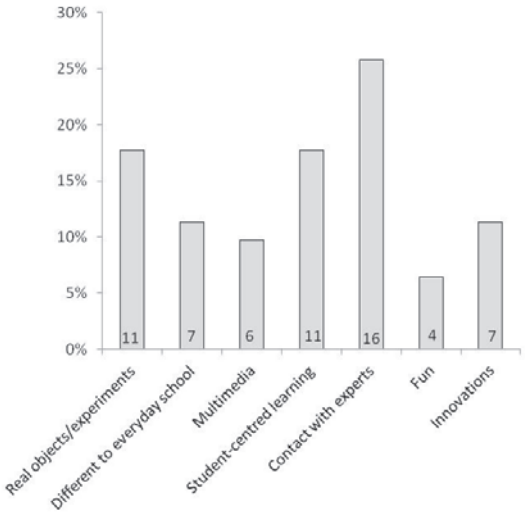

Figure 3. Results of content analysis with reference to the question: "Why did you like the lesson?" (students, n: 32). Percentages (relative frequencies) refer to total number of answers given, numbers in bars relate to absolute frequencies.

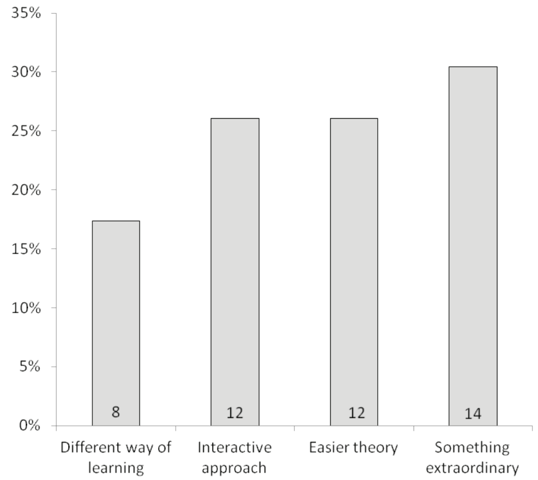

Figure 4. Results of content analysis with reference to the question: "Why did the lesson raise your interest in science?" (students, n: 32). Percentages (relative frequencies) refer to total number of answers given, numbers in bars relate to absolute frequencies.

As shown in Figure 3, students liked most contact with experts (25.8%). Furthermore they favored learning with real objects and real experiments (17.7%), same ratio of interviewees preferred a student-centered learning approach. In addition a lesson, different to everyday, school was looked upon as favorably as the innovative approach (11.3%).

The multimedia aspect was mentioned in 9.7% of cases, to a lesser extend it was stated that learning with miniatures was fun (6.5%).

Additionally, students were asked if the lesson raised their interest in science (no figure shown). Most of students answered positively (87.5%). Nobody negated the question and only a minority of students were unsure about this question (12.5%).

The lesson raised students` interest in science for different reasons (Figure 4). In a majority something extraordinary, different from everyday class (30.4%) was stated as a cause. An interactive approach, as well a simplification of theory, easier in comparison to normal lessons was mentioned to a same amount (26.1%). In addition, a different way of learning provided by the exhibits was pointed out (17.4%).

With regard to usability features students were asked, if they have had any problems concerning the usage. Only a small number of pupils (15.6%) mentioned technical problems, however the majority (84.4%) did not have problems with reference to the usage of the exhibits.

4.2 Teachers` Evaluation

Participants were asked, if they were motivated to use the SCeTGo system in their future lessons (no figure shown): 75% agreed, 18.8% would not integrate the SCeTGo approach in instruction, 6.3% were undecided.

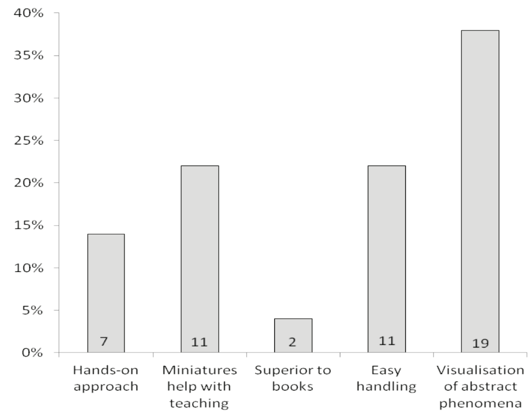

Figure 5. Results of content analysis with reference to the question: "What exactly convinced you, to make use of the SCeTGo approach?" (pre-service science teachers, n: 21; practicing science teachers, n: 15). Percentages (relative frequencies) refer to total number of answers given, numbers in bars relate to absolute frequencies.

Furthermore, in-service teachers and pre-service teachers, who indicated to use the exhibits, pointed out the most convincing features of SCeTGo, (Figure 5): A visualisation of abstract phenomena was mentioned most frequently (38%), followed by an easy handling and a support during teaching (22%). In addition, they emphasized that they liked the hands-on activities (14%). However, only in a minority SCeTGo was estimated superior to books (4%).

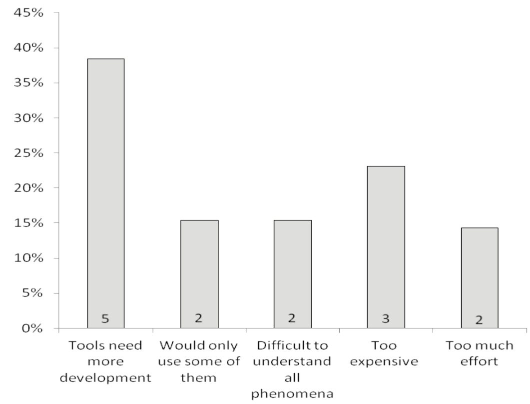

Figure 6. Results of content analysis with reference to the question: "Why don't you want to make use of the SCeTGo approach?" (pre-service science teachers, n: 9; practicing science teachers, n: 4). Percentages (relative frequencies) refer to total number of answers given, numbers in bars relate to absolute frequencies.

All in-service and pre-service science teachers, who were not willing to take use of the SCeTGo exhibits were asked for their motives, (Figure 6): In majority, interviewees referred to the prototype status of the miniatures (38.5%). Furthermore, they predicted miniatures to be to costly for an application in school (23.1%). Also some instructors found it to be difficult to understand all phenomena or would only apply some of the exhibits to practice (15.4%).

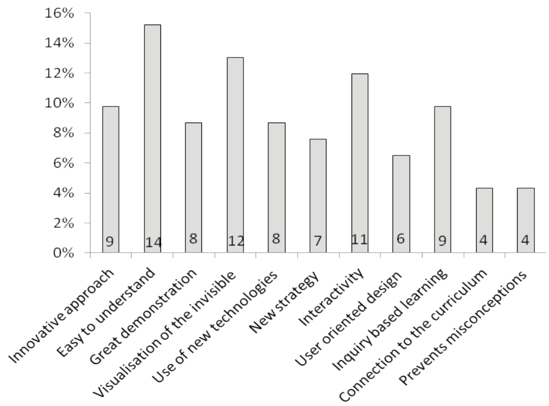

Figure 7. Results of content analysis with reference to the question: "What do you think are the most positive aspects of the SCeTGo?" (pre-service science teachers, n: 29; practicing science teachers, n: 19). Percentages (relative frequencies) refer to total number of answers given, numbers in bars relate to absolute frequencies.

In-service and pre-service science teachers highlighted several reasons, why they were motivated to take use of the SCeTGo exhibits, (Figure 7): A majority of interviewees considered the less demanding theory in context of physical phenomena as a positive feature of SCeTGo (15.2%), followed by the illustrating visualization (13.0%). Interactivity (12.0%) and an innovative approach (9.8%) were positively emphasized. In addition inquiry based learning was stated as a positive aspect (9.8%).

Further features referred to were a use of new technologies (8.7%), together with a great demonstration of physical phenomena (8.7%), a new teaching strategy (7.6%) and a user oriented design (6.5%). A connection to the curriculum, as well as a prevention of misconceptions was only mentioned in 4.3% of cases.

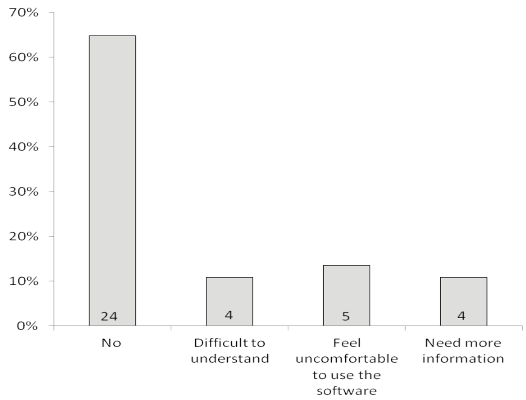

Figure 8. Results of content analysis with reference to the question: "Is there something you didn't understand, concerning the usage of the SCeTGo exhibits?" (pre-service science teachers, n: 29; practicing science teachers, n: 19). Percentages (relative frequencies) refer to total number of answers given, numbers in bars relate to absolute frequencies.

Figure 8 shows that the majority of teachers did not have problems, concerning the usage of the SCeTGo exhibits (64.9%). However, a minority felt uncomfortable to use the software (13.5%).

The same ratio of interviewees found the physical phenomena difficult to understand and need more information (10.8%).

5. Evaluation – Discussion

In the context of SCeTGo AR is used for educational purposes as a computer-mediated learning system that aims at the integration of AR technology in science teaching. Thereby, SCeTGo provides an augmented visualization aid for education.

However, in recent years technology enhanced teaching systems were questioned considering their learning efficiency. Ardito et al. [14] demanded "a synergy between the learning process and a student's interaction with the software." Furthermore "usability features should not only allow people to efficiently manipulate the interactive software, but should also be appropriate for the intended learning task."

As a consequence, the purpose of this study was to get an insight in the (1) educational value and (2) usability of an AR technology for students and teachers in order to ensure utilization in classrooms.

5.1 Pedagogical effectiveness

Pedagogical effectiveness was rated by students with regard to an increase in interest in natural science and enjoyment of the lesson. Teachers evaluated the educational value of SCeTGo and mentioned positive and negative aspects of the approach.

Overall, the feedback given by pupils within the individual interviews was positive. According the data students really liked working and learning with the miniatures. They did not suggest any improvements.

In particular, the hands-on approach of the miniatures, the student-centered lessons and the multimedia aspects was accentuated. The application of the SCeTGo miniatures raised students` interest and activated the majority of participants to get more involved in science contents. The high percentage of fascinated students shows that most of them were inspired by the exhibits and the AR technology. It therefore could engage students to get more interested in science in general.

Teachers evaluated the miniatures in combination with an AR technology as a valuable tool for instruction. They positively emphasized the interactive visualization by placing additional information (e.g. invisible molecules) into real surroundings. It was evaluated positively, as it simplifies learning and allows the learner to interact dynamically with the miniature exhibits. An active participation of the learner during the learning process is regarded as a basic prerequisite for acquiring knowledge [16]. The qualitative analysis revealed that SCeTGo simplifies instruction, what implies that miniatures have a high value to teachers. SCeTGo proposes an inquiry-based approach with a learner-specific constructivistic idea of learning. It enriches the repertoire of learning offers to more innovative teaching methods due to an AR inclusion with the specific aim to improve quality of learning. Thereby, an AR enhanced learning system, as SCeTGo contributes to a new form of education.

5.2 Technology acceptance

Results indicate that technology' acceptance is high in general and that the usability of the system is rated very positive by pupils and teachers. However requirements with regard to usability differ between these two user groups.
Balog and Pribeanu [4] for instance, had shown the perceived usefulness and the perceived enjoyment as relevant factors for students' acceptance of an AR application, while the perceived ease of use was not a significant precursor for students' acceptance. Still in contrast to students, teachers are standing in front of a class while using an interactive software system.
Therefore, teachers require a user friendly software, they could fully rely on. Consequently Ardito and collegues [14] argued that from the point of view of people, who are applying an interactive software system, usability should be the most important aspect. With regard to usability features (technical demands, user-friendliness and handling) of the SceTGo approach most educators reviewed exhibits to be easy to handle. Especially a rapid prearrangement of the setup was pointed out as a positive feature.With reference to technical acceptance, the system is easy to operate and there are no real obstacles that teachers have to overcome in order to use the system.
Yet, teachers mentioned that a system needs to be extraordinary flawlessly operational, in order to be usable at school – in some cases this was already demanded from the prototypes. Taking this into consideration, the SCeTGo technology still needs improvement to finally convince also critical teachers of its applicability.

5.3 Critical remark with regard to teachers' acceptance of AR

Science teachers play a crucial role for the implementation of AR technologies in school. Results indicate a high interest for new technologies amongst teachers in school environments in general.
Nevertheless participating teachers were not randomly chosen, since they selected the teachers training courses in order to get to know state-of-the-art technologies and to get new ideas for improvement of their instruction. As workshop participation was an optional offer, it could be the case that teachers not interested in new technologies in general decided not to participate.

In summary, all students enjoyed working and learning with the miniatures and most of the teachers assessed pedagogical effectiveness as well as technological aspects throughout positive. Usability features along with software application were rated well.
Validation could show that next to pedagogical effectiveness a user-friendly design is an important pre condition to ensure users `acceptance. Usability plays a central role to meet the requirements of teachers and students and to adapt the AR technology to the specific needs of school environments. Results emphasize that an AR system like SCeTGo has to operate absolutely reliable in order to be integrated in teachers` instruction.

Evaluation shows that introducing AR into classrooms is in line with the needs of educators and that the SCeTGo project has the potential to be applied in school environments.

It provides teachers with a tool in order to facilitate students' learning.

The highly scored interest of participants to engage in such exhibits and their learning contents is one of the important pre-conditions to improve usages of AR technologies in school. It verifies a successful future integration of exhibits based on AR-technology in instruction, which could be easily included in school lessons as long as they operate absolutely reliable.

In conclusion, the evaluation could support that the SCeTGo approach offers a modern science centre experience outside the walls of the science centre in school classrooms and thus crosscutting the boundaries between formal and informal learning. SCeTGo seems to be appropriate to integrate AR in schools and offers conditions to have an impact on education in long term.

As many examples exit in the past, when innovative approaches have proven its continued functionalities, they will make their way into classrooms anyway.

Acknowledgements

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The EXPLOAR project: Visualizing the invisible

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Abstract

The EXPLOAR project demonstrates an innovative approach that involves visitors of science museums and science centers in extended episodes of playful learning. The EXPLOAR approach looks upon informal education as an opportunity to transcend from traditional museum visits, to a "feel and interact" user experience. To this end, a set of demonstrators (learning scenarios), employing advanced and highly interactive visualization technologies and also personalised ubiquitous learning paradigms have been used. The EXPLOAR project proposes a service that demonstrates the potential of the augmented Reality (AR) technology to cover the emerging need of continuous update, innovate and development of new exhibits, new exhibitions, new educational materials, new programmes and methods to approach the visitors.

Keywords

Augmented reality, pedagogical evaluation, satellite connection, science centre, informal learning, remote visit.

1. Introduction

The EXPLOAR project [1] is a research initiative that built upon the RTD work performed in the previous years (2004-2007) in the framework of the very successful IST project, CONNECT [2]. EXPLOAR aimed to contribute significantly to the increasing demand for collaboration between schools and the informal learning sector, at a time when there is an increasing emphasis on lifelong learning and when the traditional role of the museums and science centers is being questioned and reviewed. Under this scope the EXPLOAR project aimed to contribute to the access to and sharing of advanced tools, services and learning resources, by offering unique informal learning opportunities to the visitors of science museums and science centers through the introduction and the implementation of a new technology of interaction between the visitor and the exhibition.

This technology is the Augmented Reality

(AR) technology. With AR technology it is possible to layer real objects with virtual ones and to place information into the real surroundings. Especially the possibility of AR to make convergence of education and entertainment is becoming more and more challenging as the technology is optimised and expands to other areas [3].

One of the main aims of the project was to provide the adequate field data in order to get a broad insight in the science-education value of this new augmented-reality technology with respect to formal (e.g. as part of school lessons) as well as informal (e.g. during a museum visit) learning settings [4], [5]. This was achieved through an extended validation procedure that brought together the feedback of different target groups about the project itself, the exhibits based on the principle of augmented reality and their applicability from a pedagogical point of view.

2. Project approach

The project's main technological concept was based on a personalized museum wearable system along with a series of informal educational scenarios for schools. In addition a learning environment that was developed enabled teachers, experts and students to enhance conventional teaching with natural types of learning. In order to achieve this, two exhibits from one Science Center in Finland (HEUREKA) and one in Greece (Eugenides Foundation) were enhanced with virtual content and made accessible to the visitors. The objective of the created learning environment was to address the wider possible audiences within and outside the science centre's walls.

Visitors of the Science Centers were equipped with a mobile Augmented Reality (AR) system which consisted of a portable computer and a Head Mounted Display (HMD) with an additional hybrid tracking device and two small cameras (Photo 1). This enabled enhancement of the visitor's senses; electromagnetic waves, aerodynamics, and molecular movements became perceptible in new ways. Virtually enhanced exhibits are neither susceptible to spatial nor temporal boundaries and therefore all physical processes can be transformed easily into human accessible representations. Additionally, the set-up and maintenance of such exhibits became even and even more flexible as the content could be quickly exchanged, adapted or enhanced.

From the other hand the set-up of the AR system was based on concrete pedagogical concepts. With its help additional virtual content was embedded into the real context. The system was interactive: If one manipulated the real parts of an exhibit, the virtual ones were adapted accordingly. Users could test, judge and modify their theories in an explorative manner.

Photo 1. Student wearing the AR system at Eugenides Foundation science centre

Apart from the science centre exhibits in Greece and Finland that were enhanced with augmentations and were used for the project's validation activities, the project approach foresaw the validation/demonstration of the project in a series of events and workshops that were organized throughout Europe. For this reason the developed approach was validated and demonstrated with the use of a showcase mobile exhibit. This showcase mobile exhibit was a replica of typical science centre exhibit (aerofoil) that could be transferred to any place in order to demonstrate the project's vision for the use of the AR technology (Photo 2)

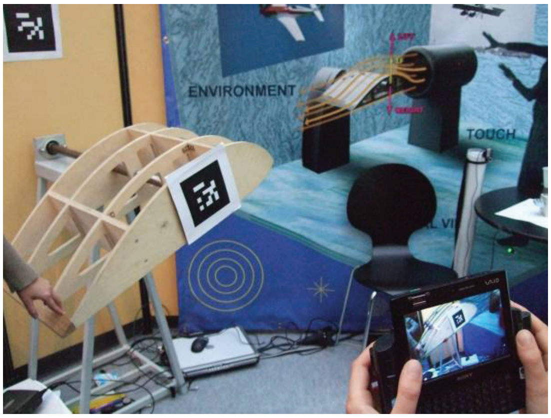

Photo 2. The showcase mobile aerofoil exhibit with the use of Ultra Mobile PCs

3. Description of the project's technology

The EXPLOAR service addresses visitors of science and technology museums, science centers and science parks. The designed and implemented activities make use of the Virtual Science Thematic Park (VSTP) which was the main outcome of the CONNECT project [6]. VSTP consists of an advanced learning environment, which acts as the main "hub" of all resources available in the participating network of science parks, science museums and research centers. The VSTP serves as distributor of information giving access to large databases, organizer of suitable didactical activities such as conventional or virtual exhibit visits or/and participation to live scientific experiments, and interconnects all the members of the network, allowing for ubiquitous access to educational and scientific resources to students, teachers and independent users from all around Europe.

The Virtual Science Thematic Park is able to provide single and multi-user (for groups as large as a school classroom) support, and includes two major components: the mobile AR system which the visitor wears/handles during his/her real visit to a museum/science park, and the CONNECT platform [6] which facilitates the virtual visits of a remote classroom/ visitor to a museum/ science park. Fig. 1 that follows gives the general architectural concept of the EXPLOAR system.

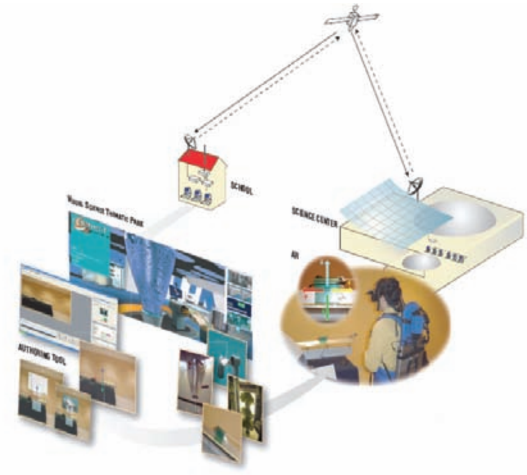

Figure 1. The architectural concept of the EXPLOAR system.

3.1 The Virtual Science Thematic Part (VSTP)

The Virtual Science Thematic Park provides personalized educational pathways for all the visitors of science and museums in many innovative ways. The system has been designed to provide 3D graphics superimposed on the user's field of vision together with other multimedia information. The role of the content creator of the system was to create educational presentations (scenarios) of the visiting pathways that different end users follow. These presentations could be thought as interactive movies, where the part of the movie that was presented to the user depended on where he/ she were located, on what his/her interactions with the system were.

The data were organized in a data base that allowed for persistency, coherence and data integrity under a number of creation/ update/ deletion operations. VSTP provides single- and multi-user support (supporting groups as large as school classrooms), accurate object registration, correct visualization of the 3D objects and web services and functionalities. The following Fig. 2 shows the overall concept and the hardware/ software component concepts in the framework of the VSTP.

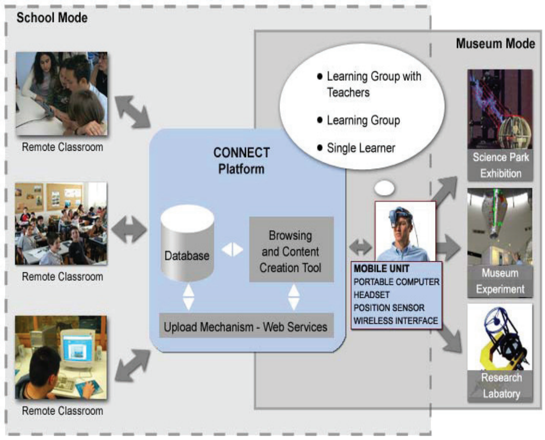

Figure 2. The VSTP concept and the hardware/ software component concepts

The Virtual Science Thematic Park Interface offers to the teachers an authoring tool (see Fig. 3), which facilitates the organization of the content that has to be presented to the students during the visit. The uploaded materials are transmitted to the AR mobile device after the teachers finalize their work and become available upon request during the visit. A pre-view facility offers to the teachers the opportunity to check the content to be presented before uploading it.

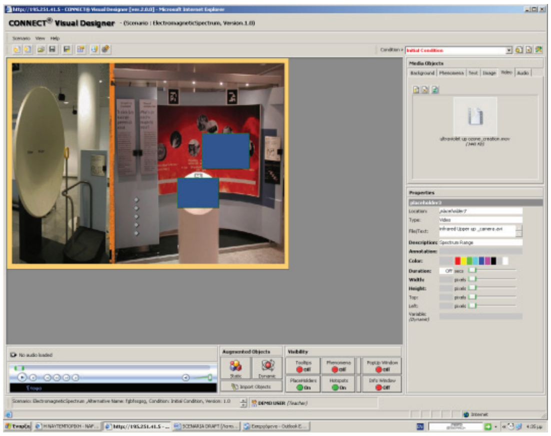

Figure 3. The authoring tool of the VSTP

3.2 The CONNECT platform concept

The CONNECT platform is of general purpose, not restricted nor depended on the number of simultaneous AR users [6]. Its facilities the users through a web interface for simplicity and further expandability. It has been designed to reduce the user cognitive load and effort, throughout the appropriate use of necessary processes in support of the task in the informal learning settings.

The CONNECT Platform [6] uses a Content Management System (database system) for storing and retrieving the learning material that consists of data, voice and video for the creation of the knowledge database. The technological requirements for the database scheme are specified depending on the data amount and the type of information. Archiving, cataloguing and indexing are specified for the creation of knowledge repository contents.

The technological infrastructure is powered, in order to guarantee the expected efficiency in terms of access speed and available bandwidth. The standards and the information that mobile AR system uses to transact with CONNECT platform specifies the types of “data objects” which are stored in the database. These “objects” provide the communication and interaction of the CONNECT platform with the users of the mobile AR system. An object oriented methodology and appropriate case tools are used. The design activities are articulated on a logical level definition, an application level definition and a physical level definition.

3.3. The mobile AR system

The mobile AR system comprised the following hardware components: a) Mobile processing unit (Laptop or Ultra Mobile PC UMPC), b) Personal display (Head Mounted Display-HMD), c) Head tracking system, d) Input/output devices. It is important to notice that during the lifetime of the project comprehensive tests of the AR system showed the need for a less intrusive system. Users were wearing a backpack holding a laptop (1st AR system version). A Head Mounted Display equipped with webcams and inertial sensors delivered the in and output devices. The system fulfilled all requirements for prototypical testing, however, for larger field tests an alternative light weight version turned out to be very useful, as the first test runs with the new mobile system were showing. Hence, the mobile AR unit evolved in order to support UMPCs (2nd version of the mobile AR system).

Ultra Mobile PCs allowed for more freedom. Either they can be used in a combination with a HMD, or as a “Magic Lens”. The UMPC can be attached to the users’ belt in combination with a HMD. Without a HMD the UMPC itself provides a window into Augmented Reality – in this case it becomes a so called “Magic Lens”. One advantage of this solution over the HMD was that multiple people were able to use it at the same time. They were able to discuss and directly interact in Augmented Reality. The UMPC could be easily passed on to other users for a better co-located experience. The AR system with the UMPC is presented in Photo 4 where the comparison with the AR system using the laptop and the backpack shown in Photo 3 in terms of user friendliness is evident.


Photos 3,4: The 1st (on the left) and the 2nd version (on the right) of the EXPLOAR AR system

3.4 Remote science centre visit using broadband satellite

Apart from the actual science centre visits the project has proposed and implemented, a series of remote visits that have been realized using broadband connections. An infrastructure which allowed a Video Stream to be sent from the Mobile AR System to a remote classroom has been put into place.

The communication used terrestrial IP networks to unicast an MPG 4 compressed, using DivX [DivX] encoded video stream. The video could be transmitted to a limited number of locations connected having broadband connections to the internet. To the video infrastructure was added an intermediary server in order to reduce the CPU load to the mobile AR unit. At the same time, this increased the number of locations which could simultaneously receive video. This was a solution which was tried and tested in the beginning of the project, but finally was left aside as it increased the complexity of the infrastructure and delays in the transmitted video.

So at that point it was decided to use alternative means of broadband communications (satellite). An additional extension to the video communication was then extensively tested in order to verify that the video stream could be sent over satellite and reach remote areas without broadband connections to the internet (e.g. Chios Greek Island). The testing proved that this video communication could indeed be sent over a satellite link with minimal loss of quality.

So a number of remote visits were implemented and four classrooms of Chios island schools participated to a live connection with the Eugenides Foundation premises and had a virtual tour to the science centre. The fascinating thing was that the remote students were able to see simultaneously what the AR user, which was physically located at the science centre, was seeing and at the same time their teachers were giving instructions to the AR user through skype, telling him to which exhibit and augmentation he/she should focus to. The whole lesson plan was designed by the remote classroom teachers in cooperation with the technical stuff of the science centre and the pedagogical partners of the consortium.

4. Pedagogical design

The EXPLOAR project proposed a new science learning scheme for all the museum visitors and introduced a technologically advanced approach for learning by connecting a wide range of learning environments (school, home, science museums, research centers, science thematic parks and exhibitions) and bridging the theoretical and applied aspects of every day personal activities. This learning scheme pointed to a free choice learning environment that demonstrated innovative ways of science communication as well as ways to augment human abilities by capturing, recalling and generalizing from situated events [7].

So the core work within the pedagogical framework of the project was the design and development of a series of scenarios of use of the EXPLOAR system. These scenarios were implemented with the use of Augmented Reality tools, and could also be regarded as paradigms of good practice that supported content delivery for informal learning within or beyond science museums for a quite diverse target groups.

The visitors of a Science Center or a museum are quite diverse. Students, teachers, tourists and experts: learning does not just happen in school but is part of our everyday life. Therefore it is important that information is presented taking the different backgrounds of the learners into account. This was realized in EXPLOAR by allowing the users to easily adjust the level of complexity of the presented content according to their needs. The content of the scenarios was presented in an open and modular way allowing for additions and improvements at any time, giving to the museum staff the possibility to make changes according to the user's feedback and the special interests of the targeted groups of visitors. This functionality was feasible because the project's software tools facilitated the creation of flexible scenarios with content that could be easily adapted to the characteristics of the visitors. In total the developed scenarios could be separated in three different categories.

a) Scenarios for the general public**:** In the science museums and science centers, the exhibits and the related phenomena were embedded in rich real world contexts where visitors could see and directly experience the real world's connections of these phenomena (e.g. environment, health). The add-on of the EXPLOAR visit (compared to a conventional museum tour) was that the visitors with the support of the system could have in their disposal an additional wealth of information. The real exhibits were mixed in their optical view with the 3-D visual objects and representations that the AR system was producing and embedding into this augmented world through their glasses.

b) Scenarios for school visits – Creating links with the school curriculum: Bearing in mind that around 40% of the visitors of the science museum are pupils with their teachers, a series of school subjects (from physics, chemistry, environmental education, applied technology etc.) was selected and presented in form of multidisciplinary educational scenarios.

c) Remote visits scenarios -Linking rural areas with science centers: The project's implementation approach has given special attention to the creation of remote visit scenarios and has devoted a significant amount of its resources to this goal by including an end user partner from a rural area of Greece that designed and implemented virtual visit. The goal was to introduce in pan-European level new ways of accessing remotely science centers and museums especially from areas that were physically deprived and whose inhabitants did not have the same learning opportunities as the people in urban areas.

From the three different categories of scenarios mentioned above the school visit scenarios and the remote ones were systematically monitored, based on a detailed evaluation methodology that focused on both students' learning outcomes and their motivation and interest. The methodology adopted foresaw: a) a school classroom performing a guided visit to the science center (conventional science centre visit), b) a school classroom performing the same visit, which was also enriched with augmented reality visualizations of the phenomena under study (AR science centre visit), and c) a remote school classroom virtually connected to the science center through broadband satellite link and following the same visit pattern with actual student visitors and having access to the exhibits and the AR visualizations of the phenomena under study (remote AR science centre visit).

Each visit regardless of its characterization as conventional, AR or remote was organized and separated in three subsequent phases. The 1st phase was the pre-visit phase which took place at school and provided a framework for interpreting which experience during the visit would occur and pointing out to what attention during the visit needed to be paid. The 2nd phase was the visit phase that could be either conventional, AR or remote depending on the visit pattern used. The 3rd phase was the post visit phase at which the visit experience was linked with the classroom's learning program. In general follow-up activities are considered important even when the actual science centre visit is not aligned with the content being covered at school. When well-designed examples of classroom follow-ups have been documented, they are in fact associated with positive educational impacts [8].

5. Evaluation results

The validation work of EXPLOAR aimed: a) to adapt a tried and tested methodology to validate products and services of the EXPLOAR project and b) to implement the validation procedure in situ in a pan-European setting.The main goal of the validation of the EXPLOAR project was bringing together the feedback of different target groups about EXPLOAR itself, to evaluate the exhibits based on the principle of augmented reality and their applicability from a pedagogical point of view. The purpose was to get a broad insight in the science-education value of this new augmented-reality technology with respect to formal (e.g. as part of school lessons) as well as informal (e.g. during a museum visit) learning settings.

For assessing the impact of the augmented reality technology on students' learning and motivation, a quasi-experimental evaluation design was implemented [9]. Three different groups of students were created, (i) a control group where students participated in a conventional science centre visit, (ii) an experimental group A where students participated in a science centre visit by using the AR system and (iii) an experimental group B where students participated in a remote science centre visit from their school classroom. In addition and separately from the above groups, general public and teachers groups were also asked through specific questionnaires to evaluate the learning impact of the proposed service.

The evaluation took place at both the science centers participating to the project (HEUREKA and Eugenides Foundation) which had two augmented exhibits (Hot Air Balloon and EM-Spectrum, see Photos 5 and 6). As it has already been mentioned these exhibits were real exhibits of the science centers that were chosen and augmented based on their proximity with the curriculum and their technical flexibility that allowed for rich augmentations.

Photo 5: Photograph of the EM exhibit in Eugenides Foundation science centre enhanced with typical augmented content for each spectral sub area

Photo 6: Photograph of a young student using the AR system with the hot air balloon exhibit at Heureka science centre

There were also additional validation activities that were organized in various workshops throughout Europe using the project's showcase mobile aerofoil exhibit. In total more than 600 questionnaires were collected and analyzed and in the following figures and tables a selection of the obtained evaluation results is given. In Table 1 visitors belonging to the "general public" test group evaluated the learning efficiency of the science centre visit with the use of the AR system.

Table1. Participants' valuing of learning efficiency of the trial ("I learned much during the trial"); scaling is from 1 = "not true" to 5 = "true"

	1	2	3	4	5
Amount [%]	0.3	7.5	22.3	58.2	11.7

Table 1 shows that 81.7 % of the total sample gave a positive feedback (scaling > 3) about the learning efficiency, whereas only 4.4 % announced to not have learned anything. 13.9 % were undecided. This can be interpreted as a somehow diffuse learning outcome which was too imprecise to be rated by the participants as factual increase in knowledge.

In the next Fig.4 the motivation of teachers to use the EXPLOAR services further on is presented.

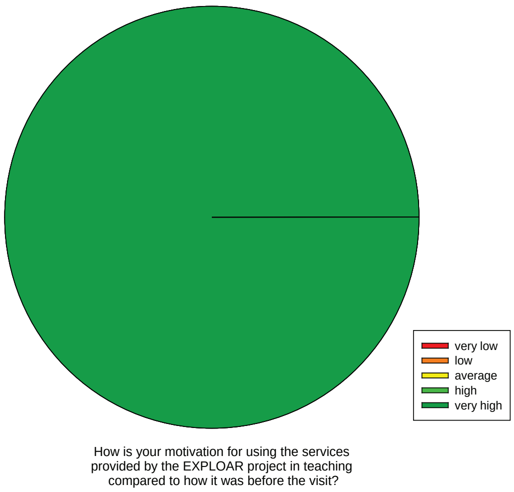

Figure 4: Distribution of frequencies in the question about motivatio for further usage of EXPLOAR services

According to Fig. 4 the motivation to use the EXPLOAR services further on was rated as “high” or “very high” by 63.9 % of the participants. 22.2 % chose “average” as answer. That is, 86.1 % of the participants can be assumed to intend to use the EXPLOAR services in their future lessons.

In next Table 2, different age groups of students that have used the AR system rate intrinsic motivation, competence and usability which were measured using the Intrinsic Motivation Inventory (IMI) [9]. From Table 2 it is shown that the students rated their interest and perceived competence as well as the usability as very high, with the only significant difference between the two age groups being the usability which the children validated it higher (median: 4.50) than the adolescents (median: 3.50)

Table 2. Medians of two age groups of students in intrinsic motivation and Usability scales; scaling from 1=very low to 5= very high

Median	Interest	Competence	Usability
Children (9-14)	4.75	3.75	4.50
Adolescents (16-17)	4.50	3.50	3.50
Total	**4.50**	**3.75**	**4.25**

Besides interest, competence and usability one item in the questionnaire dealt with self-rated learning efficiency. The students indicated how much they thought to have learned during the trial. Table 3 gives an overview of all mean scores with standard deviation calculated for the whole sample and the subsamples according to gender and age group. All these mean scores are larger than 4.00. This means that all sub-samples felt to have learned much during the trial on average. This is a very good result that shows the positive learning impact of the system.

Table 3: Mean score with standard deviation of the whole sample, and the subsamples according to gender/age group in learning efficiency; scaling from 1=very low to 5=very high

	gender		**age group**	
	male	female	children	adolescents
mean score ± standard deviation	4.27 ± 1.17	4.31 ± 1.11	4.36 ± 1.13	4.11 ± 1.17

Finally the learning outcome resulting from the statistical analysis of the data from specific knowledge questionnaires given to the students at the pre-visit phase and re-given at the post visit phase showed a cognitive achievement for both groups. That is, the group in the science centre and the group with satellite transmission learnt well using the EXPLOAR system with augmented-reality technology. As can be seen in Table 4, the difference between the mean scores for pre- and post-test is higher for the group 'satellite transmission'. But both differences are statistically significant (science centre visit: $p = 0.017$, satellite transmission: $p < 0.001$), therewith a significant increase in knowledge in both groups was confirmed.

Table 4. Mean scores with standard deviation of the different treatment groups about testing at pre-visit and post visit phase

treatment group	**science centre visit**		**satellite transmission**	
	pre-test	post-test	pre-test	post-test
mean score with ± standard deviation	1.48 ± 0.750	1.86 ± 0.727	1.54 ± 0.779	2.25 ± 0.794

The results of the learning outcome analyses confirm that the use of augmented-reality technology based exhibits for learning in science results in positive impact on the learning process through increase in knowledge. Gain of basic factual knowledge was enhanced for both the group on-site and the group using satellite transmission. Based on these findings we could assume that a science centre visit as well as a satellite transmission provides an 'added value' for learning in science based on augmented-reality technology exhibits. The successful implementation of the satellite transmission can therefore be considered as another important application to 'bridge the gap' between formal and informal learning.

In general, based on the results from different target groups, considering affective-emotional aspects as well as usability aspects, we can conclude that the AR-technology based exhibits and the EXPLOAR approach are appropriate for a wide range of people, almost independent from their age, gender, stratification level, and reason for visiting the science centre. The above results are coherent with previous findings that come up with similar conclusions [10].

6. Acknowledgements

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Melting Interfaces – Learning in Mixed Realities A Retrospective on Transitional Objects

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Abstract

This paper takes a retrospective look at computer mediated transitional objects. First existing constructionistic approaches are analysed. A perspective on the concept of using the computer as a transitional mediator is given, and major requirements and challenges are described. Then we elaborate on the basic approach of transitional objects and discuss possible extensions, by taking nowadays technical advances into consideration. We propose to extend the basic object based model by actions, and outline the concept of artificially extended computer mediation to reach new target domains. We argue why Mixed Reality technology may help to overcome some constraints of complex authoring systems to provide a universal object and action representation. Finally we describe the two prototypical test systems AR-Minigolf and RobertAR for further investigations on revealed challenges.

Keywords

Augmented Reality, Tangible User Interface, Transitional Objects, Computer Mediated Learning

1. Introduction

Ever since human beings are able to learn they seek for ways of improving it. Countless models on human learning have been elaborated, numerous techniques have been developed and evaluated; the fundamentals of learning still remained the same.

While our learning mechanisms remain, the development and appearance of computers changes rapidly. In the last three decades their ubiquity and their real world interfaces advanced in a way that we interact with computers through various objects almost anytime and anywhere. Computers are getting smaller and they are part of objects we use every day, such as cars, ovens, or even clothes. Moreover their input and output interfaces extend in a way that they allow for multi modal interaction; computer input went far beyond mouse and keyboard. We communicate via body motion or spoken language. GPS, gyroscopes, time of light cameras, and speech to text are common input modalities. Display techniques advanced in a way that stereo 3D is becoming common, even without glasses, and virtual information may be displayed on almost every object, becoming part of reality.

Therefore we decided to re-consider the constructionistic development starting with Papert's transitional objects, from today's technical perspective. We believe that most recent technical advances, especially in the areas of Tangible User Interfaces (TUI) and Augmented Reality (AR) have very high potential to improve constructivistic learning environments.

In the following text we will elaborate new perspectives on computer mediated learning. Such views are meant to help improve existing constructionistic systems, and unleash the power of AR and TUIs for the development of new computer mediated learning tools.

2. Background

Our work is heavily based on constructionistic work done by Papert, Kay and Resnick.

In his book "Mindstorms" [10] Papert elaborates on gears as a Transitional Object (TO) (also compare [15]). Papert developed an affection for cars and everything associated with cars when he was a young child. This favor led to a distinct interest for gears, on a functional and emotional level. He projected many abstract problems onto his beloved gears, to give problems a connotation of pleasure. Piaget's work provided the epistemological basis for Papert's view on gears. Piaget formulates the concept of a progression from concrete to abstract during children's stages of knowledge development, where children construct concrete operations first before they construct formal operations [11].

Thus, based on a very strong emotional connection, gears gave Papert access to abstract mathematical ideas, while at the same time being connected to sensorimotor body knowledge. Papert was able to project himself into the place of gears to joyfully map abstract information on concrete objects. This way, they carried "powerful" mathematical concepts into his mind.

While gears gave good access to mathematical models for Papert, he was looking for a universal Transitional Object, which he found in the simulation power of computers. In this context he worked on LOGO Turtles. LOGO Turtles are programmable real robotic objects, equipped with a pen to trace their movements. For the programmer the position, orientation, and pen are accessible. This way one can implement algorithms for drawing shapes and other structures. Drawings are programmed through procedural commands telling the turtle on how to proceed from its current position. The programming of procedures to draw geometrical shapes gives learners access to higher mathematical concepts, such as the angular sum of triangles or the importance of number pi. Later, when displays became less expensive the physical turtle was more extensively used in a virtual variant [15], within the so called turtle graphics.

Another constructivistic learning environment, building on programming computers, is Squeak. Squeak is a Smalltalk based authoring environment inspired by LOGO. It offers a full featured object based hypermedia environment for creating, accessing, and changing simple text, movies, sound, or even 3D virtual content. Squeak aims for a simple but powerful graphical user interface, allowing its users to adapt all parts of the system. Users may simply interact with given parts of the environment, modify existing objects, or create own simulation models and tools. The environment is meant to provide access to various levels of complexity, meeting the needs of novices as well as experts. This way Squeak seeks to offer the "low floor" and "high ceiling", as postulated by Papert [13]. Squeak is open source and its community offers a variety of programming and authoring tools. One kind of such tools is Etoys. An authoring environment which enables digital novices to create simulation models from a set of building blocks [6].

A specialization of Etoys may be seen in Scratch, which consists of a Squeak environment fully dedicated to programming with building blogs. Scratch is well connected with a web community platform for sharing projects [13].

While Scratch, Etoys, or Squeak focus on advanced Graphical User Interfaces, several other projects advanced the tangible idea of transitional objects described by Papert.

In this context Resnick et al. [14] introduced Digital Manipulatives, which put emphasis on learning with physical objects. The basic concept is the integration of computational and communications capabilities in traditional children's toys. Information technology is implemented into toys for playful and experimental learning. The idea mainly focused on extending toys in a way that they can be programmed. Therefore, programmable bricks, so called "crickets" where embedded into different kind of toys. These could be programmed, and even communicate with each other via infrared. As an example a common ball is equipped with a color LED, an accelerometer, and a programmable brick. The cricket could then be programmed to react on different ball movements detected by the accelerometer. This way "mood" could be mimicked by displaying a motion related changing glow.

A similar approach is undertaken by Lego with their so-called Mindstorms [7]. Mindstorms extend normal Lego blocks by adding motors, cameras, sensors and even a mini computer. Such computers can be programmed enabling the building of a variety of different creations, which typically resemble simple robots [1]. By using Lego Mindstorms children take first steps into programming. The usage of light or temperature sensors on the other hand enables them to learn about other traditional physics topics (also compare [5]).

Another example for a Digital Manipulative is given by Topobo. Topobo allows learners to create real robots from a small set of simple generic building parts. The joints of these parts include servo motors, which are wired to electronics inside the housing of each part. Learners can connect multiple robot parts to bigger creatures. Such creatures are able to record and playback movements. For recording the learner simply switches connected parts into record mode, and haptically implements a movement [12].

Technically Topobo makes great use of the ideas of Tangible User Interfaces (TUI). They enable the user to interact with the computer in a natural way. Instead of using mouse and keyboard the appearance, position and orientation of physical objects is interpreted by the computer, allowing for new input devices [17].

Many more constructionistic approaches are building on tangible learning tools [9]. Recent approaches such as the Science Center To Go showed high potential in combining TUIs with Augmented Reality (AR) technology to enhance science teaching with a hands-on learning experience [3, 4].

3. Concept

In our concept we will first have an analytical look at Transitional Objects (TO), and transfer such findings into a retrospective from today's technical possibilities.

We determined the following fundamental schema behind TOs and their successors. The main goal of Transitional Objects lies in their function of helping learners in acquiring new knowledge domains. This function may simply be achieved by raising interest for a new target domain. As previously detailed, Papert's love for gears gave him access to abstract mathematical models [10]. Thus, an object rudimentarily works as a Transitional Object, if a learner has a strong emotional connotation to an object, which is used to interface a new domain.

The transitional object needs to be known to the user and also be connected to the new matter. Therefore, it should be part of the learners' knowledge and the target domain as shown in Figure 1.

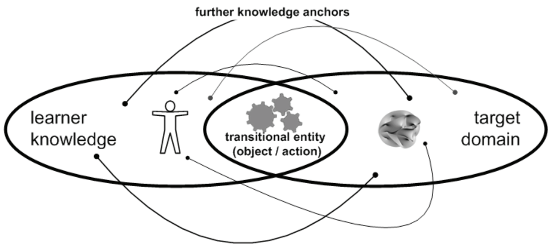

Figure 1. The transitional object interfacing the learners knowledge and new domain. The area of intersection should be sufficiently big.

The figure also symbolizes the fact that learners usually also have further knowledge anchors to the target domain, apart from the Transitional Object.

For Papert it is also important that such objects are tangible. The embodiment of gears, for example helped him to project himself into them. However, in our view the transitional effect is not limited to tangible objects, and should also include actions. For example, dancing, singing, hiking, or playing an instrument, might help in acquiring otherwise uninteresting domains more easily. Oftentimes, one is not affected to an object but to its behavior. For instance, a ball would lose much of its attraction as a toy if it loses its predictable behavior. Extending the idea of Transitional Objects by actions also extends the number of accessible target domains. Physical objects often limit the target domain to physical problems, which makes subjects, such as social interaction, sometimes hard to address. In the further text we will refer to transitional objects and actions as Transitional Entities (TE).

Figure 1 also indicates that the area of intersection on both sides needs to be sufficiently big. While great user knowledge about an entity of interest is very likely, it is harder to ensure sufficient coverage of the target domain. Hence versatile affection seems to be advantageous, in order to select from multiple TEs the best one fitting a certain domain.

Since affection is a cognitive state which is intrinsically developed by each individual, it might also be wise to build on existing affections, instead of trying to mediate new ones. It is hard to think of something that everyone is affected to. Consequently, the computer only works as a transitional object for someone who already has affection to computers or programming. This rises the following question: Does only a minority of computer enthusiasts profit from the universal power of computers to simulate everything? If this were true, than objects like Topobo, Mindstorms or Squeak would have a very limited natural target group.

Topobo, for example, does not only work for boys who like robots, it could as well be affective for girls who like cats. In this case, the cat is the Transitional Entity mimicked by a Topobo robot. In the same way Squeak could be interesting for someone who likes airplanes. Squeak offers various tools to create representations of objects. For example, an airplane could be drawn on the screen and then extended with aeronautic behaviors. The plane would still serve as Transitional Entity mediated by Squeak as a carrier to represent the object and its behavior.

The power of the computer to simulate everything can be used in both directions: on the one side to access the target domain and on the other side to mimic transitional objects. In this sense the computer is not a transitional object, but serves as a universal mediating interface as shown in Figure 2

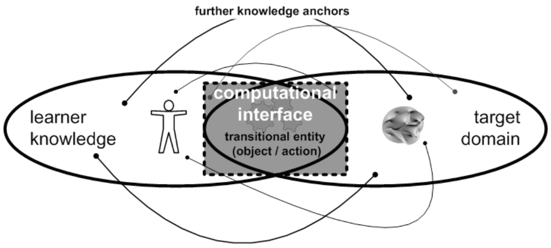

Figure 2. The computer as a mediating interface into both directions. On the one side mimicking a Transitional Entity, on the other side extending interfaces to new target domains

The human computer interface should ideally be as close as possible to the represented TEs interface. In the worst case it is not only different, but it also lies outside the learners knowledge.

Theoretically computers are able to represent every transitional object, from gears to the solar system. Computers also allow for the representation of actions and behaviors, such as evolutionary or cognitive theories. However, they are only simulating; learners are not directly interacting with their Transitional Entities, but with the computer interface, which usually differs from the interface of the TE (also compare Figure 1 and Figure 2).

There are two forms of discrepancy between the TE's and the computer interface, which could lead to a crucial loss of affection. On the one hand the representation is too unrealistic or abstract to convincingly represent the Transitional Entity. On the other hand the computer interface could exceed the abilities or knowledge of the user, as visualized in Figure 3.

Squeak, Logo or even Scratch are likely to be too abstract for learners, compared to simpler haptic TE mediators, such as Topobo, because their interface is more complex and less intuitive. While Topobo is very haptic and authoring is comparably intuitive, it lacks flexibility in addressing target domains.

There are also several advantages of using a complex system. Their flexibility allows for representing a bigger variety of actions and objects. An object such as an airplane is hardly represented by Topobo, for example. Moreover, representations can become more profound with rising complexity. The simulation of a cat with Topobo surely cannot be as accurate and comprehensive, as the simulation of a virtual cat using Squeak. Whether a more accurate but intangible simulation is favored by the learner, stays unclear and should be further investigated.

Another interesting aspect, which might not be desired at first sight, is the extension of a Transitional Entity towards untypical domains. Actually, such extensions happen in science whenever a new feature of a certain entity or a new perspective on a given aspect is discovered. For example, when it was discovered, that the Earth is not flat, this opened up a whole new set of new domains for everyone who was affected by geography. In the same way one could artificially extend computer meditated TEs to open new target domains, as illustrated in Figure 4.

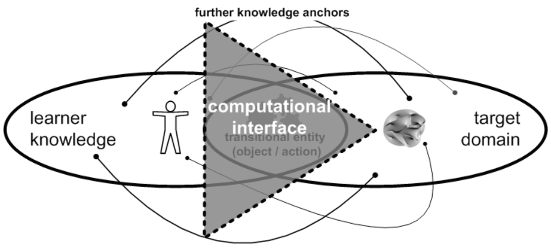

Figure 3. Unfavorable computer user interface: The interface is either to complex or too abstract to represent the Transitional Object.

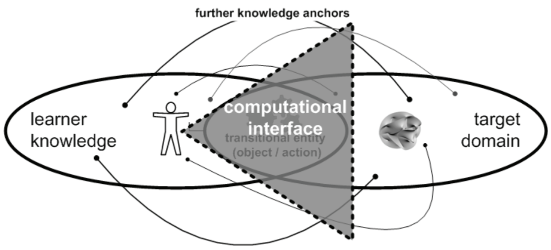

Figure 4. Artificial extension of Transitional Entities to address uncommon new domains.

An example for such an extension could be based on colors as TE, when they are extended by the computer through a frequency mapping onto the sound spectrum. This could open target domains located in physics or math to someone who is actually interested in painting and art. The procedure of extending objects or actions to address new target domains raises multiple questions, especially regarding user acceptance. However, computer mediated extension of transitional objects or actions seem to be promising, and may hold some yet unrevealed potential. Therefore, we decided to create a test case scenario on that matter for further investigations. We decided to build a use case around augmented minigolf. The first prototypical implementation and further possible examples for this use case will be given in chapter 4.1.

Our second focus lies on complex authoring environments, such as Squeak or Lego Mindstorms. From our view such environments are most valuable, if they manage to reach the learner. Their biggest challenge is their biggest advantage: with increasing user interface complexity they easily overstrain the learner. Representations for transitional objects become too abstract. We believe that recent technological advances may help to overcome this problem. Hence, in our second test case scenario we created a prototypical Lego Mindstorms extension through Augmented Reality (AR) technology. We believe that AR gives many possibilities to provide more concrete representations of Transitional Entities. AR easily allows for changing the look and interaction of real world objects. The ability to quickly create representations of objects and actions seems to be very important. We also see a great chance in using AR technology to build new authoring techniques, if we are learning from environments such as Squeak and Scratch in consideration of our new possibilities.

4. Prototypical Implementations of Melting Interfaces

In the following we will describe the two prototypical test scenarios mentioned earlier: AR-Minigolf and RobertAR.

AR-Minigolf provides us with an experimental ground to test the abilities of Augmented Reality for addressing multiple target domains from a fairly simple transitional object.

With RobertAR we created a more complex test ground, which aims at improving a complex user interface through AR. Its generic appearance allows to mimic multiple Transitional Entities. We plan to use it for investigating new interaction paradigms, which enable authoring for digital novices.

4.1 AR-Minigolf

Minigolf itself, serves as a great Transitional Entity for accessing multiple mathematical and physical concepts related to reflection, forces, or momentum.

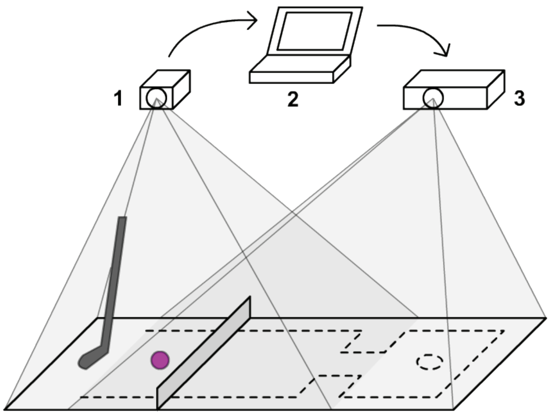

Figure 5. Schematic system setup showing 1) camera, 2) computer, 3) projector

The AR-Minigolf application extends a normal Minigolf game to an interactive learning environment. Good minigolf players should be more skillful in playing AR-Minigolf than untalented players, since its interaction does not differ from the mimicked original. Users may even use their favored golf putter to play the game. An ordinary golf ball is shot onto a partially virtual course.

Technically the position of the ball during the interaction is tracked using a webcam. A single colored standard golf ball with a defined size simplifies and improves the quality of tracking. The ball's position is recorded and transferred to the simulation where it controls a virtual representation.

Virtual obstacles are adjustable and an unlimited variety of tracks may be configured. Based on this information a physics simulation is calculating the new position for the virtual ball. The visualization is generated accordingly and the video output is transformed to ensure a correct matching of the virtual and real ball. In the last step the generated visualization is projected using a data projector (see Figure 5).

Different modes and scenarios of playing are available. Concerning real obstacles on the playground, the system is used to visualize the ball's behavior. Instead of analyzing the route of the ball afterwards, the track is recorded and displayed in real-time to support the learner's cognition and the coherence between an abstract line representation and the real behavior. Additional information such as direction, speed and a predicted track can be visualized. In this scenario all interaction take place in reality and the virtual representation is mapped one-to-one.

In a second mode the real ball triggers a virtual simulation, as shown in Figure 6. The ball's initial direction and position is tracked, analyzed and seamlessly transformed into a virtual simulation. By using a projection mapped onto the ground, all obstacles are visible to the user in real size. This generates a complete environment, where the testing within the virtual simulation becomes less abstract. The user is required to plan his way of acting in consideration of the virtual course.

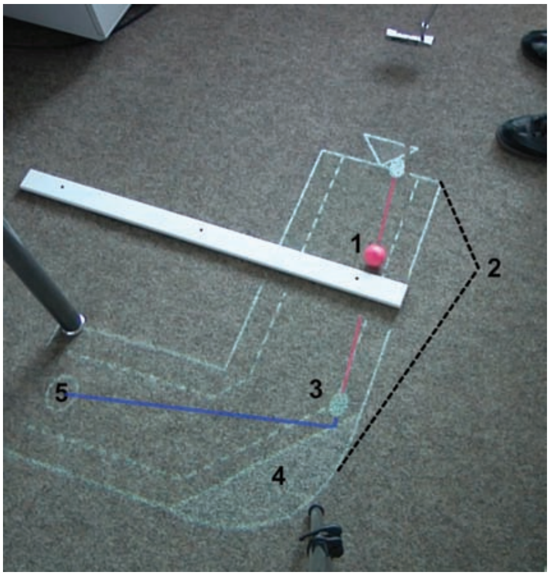

Figure 6. System in use with 1) real ball, 2) projected course, 3) virtual ball, 4) virtual obstacle, 5) hole, 6) stopper

Additionally AR-Minigolf can be used as competitive tool to play and solve different courses. The flexibility is almost unlimited as a virtual set is used. Another way of usage is to present a course that is not playable with a hole-in-one. In this complex situation students have to modify the arrangement of obstacles to create a playable version based on the theories learned. The projected playground is visible to all players at the same time, which helps to discuss while solving a task.

All scenarios enable the learner to hypothesize the behavior of the ball depending on direction, speed and obstacles and directly test and evaluate it. The interaction with the software is based on a natural way of interaction with the club as a tangible user interface. As the visual feedback is projected no additional devices are necessary to see the virtual course. The simulation seems to take place in the same environment.

AR-Minigolf delivers a very natural user interface, as it is required to meet the demanded test case as shown in Figure 4. The virtual environment allows for various extensions that go beyond standard physical and mathematical concepts. One could for example create a scenario where the golf ball hits a number of smaller balls, and ask questions similar to the questions that scientists are confronted with working at the LHC.

The virtual setup also allows for opening the domain of art and design to someone who might be rather interested in physics. The virtual playground could be a painting where players get the task to play the ball in a way that its track cuts the painting in two visually balanced parts. Another goal for a course could be to play the golden section.

Many more scenarios are imaginable, and probably all major disciplines can be addressed through augmented minigolf courses. The major question that arises for the future is, whether AR Minigolf then still is perceived as a Transitional Entity, or whether it loses affection?

4.2 RobertAR

With RobertAR we are embedding fully programmable Lego Mindstroms robots into a virtual augmentation of reality. Interaction with such robots is tangible and includes full force feedback. By extending Lego Mindstorms with Augmented Reality we give the system and their users the chance to overcome its physical constraints – and we get a test bed that helps us evaluating tangible AR in comparably complex authoring systems.

The RobertAR project extends the project Roberta [5] and builds on the LEGO Mindstorms [7] kit for autonomous vehicles. In RobertAR the Lego robots are tracked via a camera based computer vision system. This allows to virtually enhance the robots' environment. Depending on the scenario, projection mapping is used to visualize elements of the augmented scene. Additionally handheld devices are used for a close three-dimensional look.

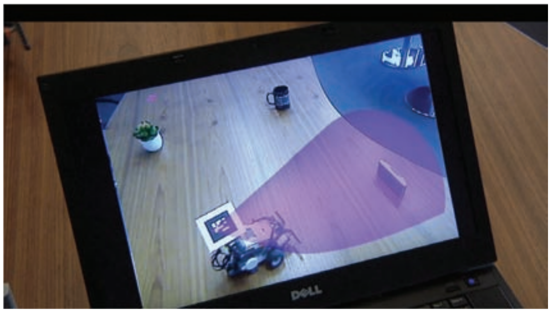

Figure 7. Augmented view on Lego Mindstorms robots. Sensor data is visualized as well as virtual objects are embedded into the real environment.

A major goal of this setup is to improve the system's ability to provide more concrete representations of Transitional Entities. Due to AR it is easy to change the appearance of robots in an unrestricted manner. Robots can be virtually dressed as anything imaginable. This way a robot can take the look of a simple ball, a certain person, or ungraspable elements such as fire. This is one example of many more potential ways to improve the concreteness of TE representations.

Our second goal of this test case is to research new authoring methodologies in such an environment. In a very first approach we are trying to create some tools which proofed to be helpful in graphical authoring environments, such as Squeak or Scratch. A Graphical User Interface system, for example, would be able to visualize the robots sensor beam, which is invisible to users of real Mindstorms robots. An AR visualization of the ultra sonic distance measurement sensor is shown in Figure 7.

From LOGO Turtles we know that route tracing is a very powerful learning extension. We implemented this functionality into our RobertAR system. If activated, the system tracks the robots route and superimposes reality with virtual track information. This helps to understand robot movements and allows for the comparison of different runs. Unlike logo the route tracing does not demand the robot to run on special drawing material, since information is augmented virtually. This opens ideas for many new scenarios, for example in a scenario where Robots which perform identical movements on different undergrounds are tracked. Any offsets would be caused by the ground. This could open a geological domain to users who were initially not interested in this domain.

The possibilities of the RobertAR system seem to be endless. Investigating such a tangible augmented reality environment brings up ideas for new authoring interaction techniques. Our first tests indicate that the RobertAR environment seems to provide the right flexibility to continue our studies on this subject.

5. Conclusion and Future Work

In this text we presented a retrospective analysis of Transitional Objects, as Papert elaborated them. In our analysis we proposed to extend the idea of Transitional Objects to actions, which we put under the umbrella of Transitional Entities (TE). We highlighted the following aspects of TEs:

- TEs comprise objects and actions users are affected to
- TEs support learners acquiring new domains
- TEs are sufficiently big areas of intersection between user knowledge and a certain target domain

Although the computer can be a Transitional Entity, we rather accentuate its distinct role as a medium for TEs. In this context we outlined an important discrepancy of complex and simpler computer mediating learning systems: while complex systems have the power to mimic every TE, their complexity might at the same time increase abstractness. Learners are overstrained, and lose connection to their transitional objects. We pointed out why Augmented Reality technology may help to overcome this constraint. Additionally, we found potential in artificially extending real TEs to address new target domains. For both predominant challenges we created and described prototypical test beds: RobertAR and AR Minigolf. The test beds should help us answering future questions.

Regarding the idea of artificially extending TEs to new target domains a major questions is whether this might also add abstractness to the representational object. In future work we will be creating a spectrum of minigolf levels, trying to determine the boundaries of artificial extensions. In this context we will also research on the key features for keeping concreteness and affection.

Another important question is how AR increases acceptance for TEs. It is left for future work to find out what kind of realism learners prefer for their TEs, and how to measure the realism.

Finally, further conceptual and analytical challenges have to be approached to design new AR based interaction techniques allowing for non expert users to quickly create TEs.

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Enabling mobile learning experiences for architecture education

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Abstract

In the field of architecture education, a large amount of learning resources is enriched with geoinformation. Location-based services on mobile devices allow for providing such information not only in a virtual space, but in real, mobile contexts, taking into account the user's current location. Based on the service infrastructure developed within the MACE system, several approaches to provide learning resources from the field of architecture on mobile devices have been realised. This entails a blended learning scenario, informal learning settings, and also new means to disseminate MACE and the MACE contents within established, widespread mobile applications. We will present these approaches, the potential benefits they offer, as well as technical details about their realisation. The evaluation results for the blended learning scenario finally give an indication of the successful applicability.

Keywords

Access to learning resources, Augmented reality, MACE, Mobile applications.

1. Introduction

Mobile technologies allow providing information about real life objects such as places and buildings not only in a virtual space, but also in real contexts, based on the user's current position or even bearing. Consequently, learning resources that are enriched with geoinformation can be used in a variety of new (learning) scenarios. In the field of architecture education, this is of special importance, as large amounts of learning resources from this domain are related to real world objects such as buildings or construction sites. The MACE system provides access to such contents from diverse repositories.

Mobile technologies can potentially promote, facilitate, and enhance student collaboration and interaction -- processes that serve as a means for accessing, discovering, discussing, and sharing information. Therefore, mobile technologies extend learning beyond classrooms and homes to any possible site such as airports, train stations, markets and the outside world in general. Moreover, mobile devices with cameras permit students to photograph buildings, construction elements, construction sites, etc. and serve as a means for sharing interests with friends. Thus, students can pose questions, collaborate with classmates, and learn new knowledge. As such, learning using mobile devices becomes a useful and attractive tool to be used in the field of architecture, as it combines mobile computing with e-learning, integrating individualised or personal learning with any-time, anywhere learning [1].

Besides learning scenarios, many location-based services that provide information about nearby events or places such as sights, restaurants, and shopping facilities have grown in popularity. By offering MACE contents within such services, new means to disseminate MACE can be realised in order to further promote the system was well as the integrated repositories.

In the following, we will first provide a short overview of the MACE system and its underlying architecture. Then, the blended learning scenario using mobile technology in higher architecture education provides insights into the successful application of location-based services for learning. Finally, two further scenarios that use MACE learning resources for mobile, informal learning settings are presented. We will conclude with a summary and an outlook on future work.

2. The MACE system

MACE (Metadata for Architectural Contents in Europe) is a European Initiative aimed at improving architectural education, by integrating and connecting vast amounts of content from diverse repositories, including past European projects and existing architectural design communities [2,3].

Relevant learning material for the domain of architecture is scattered over many repositories that are not related with each other. Hence, students and teachers have to know about the various repositories and their specifics, have to access them separately and, in general, are not able to easily find and retrieve appropriate learning resources. Furthermore, the repositories use different terminologies and classifications to describe and classify their resources. Thus, accessing information is difficult and time-consuming for users.

Within the MACE portal that is publicly accessible (http://www.mace-project.eu), searching through and finding appropriate learning resources from a variety of sources is enabled in a discovery oriented way. By automatically and manually linking learning resources of various non-related repositories with each other, users are able to discover new learning resources that serve as additional sources of inspiration and support reaching desired learning goals. MACE was made available to the public in midyear 2009, and evaluation results have shown the validity of the approach for several learning scenarios [4].

MACE provides a variety of searching and browsing facilities that rely on the metadata associated with the learning resources. The system offers a filtered search where a user is able to qualify the search with several additional facets that describe the context of the learning resource(s) in question, to browse by classification based on the MACE taxonomy, to browse by competence based on a competence catalogue, to browse by location allowing to specify a map section to see which contents have been associated with locations in the respective section, to conduct a social search based on tags that have been associated with resources by end users, and to browse user portfolios of learning resources.

2.1 MACE system architecture

The MACE system relies on the description of learning resources with metadata. The metadata is provided either by learning repositories that join the MACE harvesting federation, by users through the MACE community features, or through (semi-) automatic metadata enrichment, e.g. coupling MACE metadata with sources like Wikipedia. In order to enable this kind of flexibility, the conceptual and implementation approach of MACE builds on the service oriented architecture (SOA) paradigm. As such, the 3-tier structure is composed of user interfaces and widgets in the client tier, the back-end tier with its metadata and data stores, and finally the application-server tier inbetween. The application-server tier provides the necessary services in terms of access to and management of metadata and data as well as the processing, tailoring and reformatting of data for the purposes of the client tier [5]. See [6] or [2] for a complete overview of the overall system architecture.

Following the SOA paradigm, the tiers communicate with each other using Web Services and Ajax. Common data formats and standards ensure the reusability of backend services across systems and contexts of use, e.g., through JSON, LOM and KML. Consequently, and demonstrated in this paper, new services are able to rely on MACE services even though the new services were not explicitly foreseen when MACE was conceptually designed.

3. MACE mobile learning scenario in UPC courses

In this blended learning scenario, mobile devices were used to enable students to create learning resources of real-world objects, may that be buildings or specifics of a building design. For a thorough discussion of the notion of real-world objects, please see [7]. The learning resources were discussed in class, so that the teacher and students were able to reflect on the correctness and completeness of resources. The course on architecture design took place as part of the curriculum of engineering at the Technical University of Catalonia (UPC) in Barcelona.

The blended learning scenario consisted of three phases, all making use of the services of the MACE infrastructure.

The first phase of the scenario took place in the classroom where students were taught the concepts they would use during the second phase.

During the second phase learners went out in the field provided with the mobile devices. In this mobile learning phase, students explored a group of characteristic buildings of the city to identify the construction elements, materials, and constructive methods they learnt before. The exploration took place on the basis of a map indicating interesting real-world objects in the vicinity of the students' location. Photographs of real-world objects (buildings) were made, which were also tagged to identify interesting parts of those buildings. In addition to that, students could view the tags created by other students and comment on them. The content created during this phase was then used in the last phase.

During the third phase, which again took place in a classroom, the photographs, tags, and comments made by the students and stored in a web database were used to spark a discussion and to correct the students where necessary.

The last phase was aimed at evaluating the results of the experimentation.

The software was evaluated in this blended learning scenario with five students at UPC. All of them had already studied different courses related to construction elements, construction materials, and constructive methods. The participants had never used an application similar to the ContextBlogger that will now be presented before.

3.1 Mobile clients

A web-based system called ContextBlogger was designed and built to support the learners in their mobile context, allowing them to learn whenever and wherever the students are. Its design is based on the above described blended learning scenario.

The ContextBlogger mobile client is the mobile application to create and annotate geo-tagged pictures. It runs on the students mobile devices and offers the following functionalities:

- Create a Real World Object (RWO) with an associated GPS coordinate
- View RWOs in the vicinity of the users
- View a list of available photographs of an RWO
- Create photographs for an RWO
- Tag photographs with text tags
- View tags for an RWO, also those created by others
- Comment on tags

The ContextBlogger web portal is a web portal where all the pictures taken with the ContextBlogger mobile client are stored and shared by the users. It offers the following functionalities:

- See the list of pictures and RWOs created by all the users
- See the tags of the picture added using the mobile phone
- Add a title and comments to the picture
- Punctuate the picture
- Store all the pictures taken or tagged by the user in a personal space

3.2 Experimentation description

The experimentation was designed following the scenario aforementioned. Each student was asked to identify the main characteristic elements of different characteristic buildings of the city of Barcelona such as Sagrada Familia, Franca Station, Hotel Ars, La Pedrera, etc. The five students and the person responsible for the experiment spent one afternoon in Barcelona. Students used the mobile phone with the ContextBlogger installed to take pictures and tag them freely. These students profited from the GPS information to move from one building to the other. Once back at the university, students were asked to log in to the ContextBlogger portal and check their tags as well as inspect other students' contributions. Finally, students had to evaluate the system. The screenshots presented in Figure 1 illustrate some of these use cases.

Figure 1. Screenshots from the UPC mobile client, in clockwise order: Create an RWO, RWO photographs, View RWO tags, List of pictures, Picture's tags, User space

3.3 Evaluation of the software

According to Sharples [8], mobile technology for learning should be evaluated on the basis of three aspects: Usability, for which the standard online instrument AttrakDiff was used to measure usability, Effectiveness, and Desirability, for which the Microsoft Desirability Toolkit [9] was used.

The focus of the qualitative evaluation focused on the evaluation of usability and desirability. The usability evaluation was carried out first; the students were asked to fill out the web-based AttrakDiff survey. Then, the Microsoft Desirability cards were used to measure the desirability of the software and to acquire some additional remarks from the students regarding the reason they chose those cards. And finally, the usefulness of the system was also evaluated using a questionnaire adapted by [10] and [11]. New items were added in this study to measure not only the usefulness of the system but also the students' satisfaction. This 24-item questionnaire focused on the usefulness of the ContextBlogger for increasing students' interest in construction issues. Respondents could rate each item on a 1-5 Likert scale from "I completely agree (5)" to "I don't agree at all (1)."

3.4 Results

This section presents the results of (1) the usability evaluation carried out with the AttrakDiff toolkit, (2) the results of the desirability evaluation carried out with the Microsoft Desirability Toolkit, and (3) the results of the questionnaire for usefulness and satisfaction. All results were based on an evaluation carried out with five students at the Technical University of Catalonia.

3.4.1 Results of usability evaluation

The usability evaluation showed that there is definite room for improvement of the software, especially because the user interface was rated as "neutral". Moreover, the impression of the product was moderately attractive, and should the students be bound to the product more strongly, it should be improved. Figure 2 shows the mean ratings of the word-pairs in the usability questionnaire, the aforementioned impressions were based on. Especially, the outliers in Figure 2 are interesting because they show the word-pairs the students felt most strongly about. On the one hand, on the negative part of the rating scale, the product is rated as "technical", "cheap", and "ugly", features that relate to the usability and appeal of the product and that should be improved in a next prototype. On the other hand, on the positive part of the rating scale, the product was rated as "inventive", "creative", and "innovative". These features relate to the purpose of the product, and emphasise that the students did consider the product as useful, although there is room for improvement.

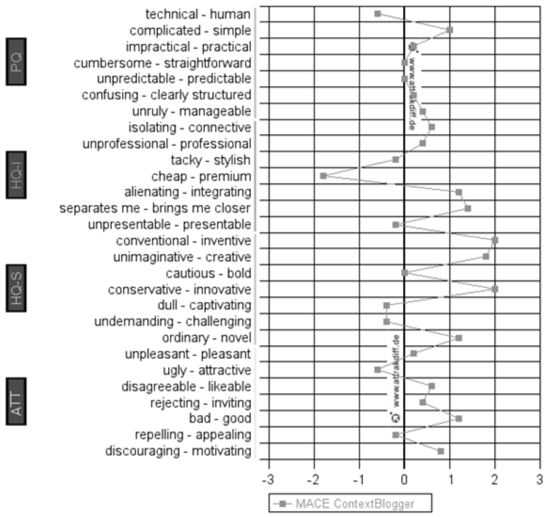

Figure 2. Mean ratings of the word-pairs in the usability questionnaire

3.4.2 Results of desirability interviews

The desirability evaluation results are presented in Figure 3, which shows the number of times a term was chosen to describe the product. All the terms that were chosen by the students are listed on the y-axis. The term “Slow” was used by all students to describe the product, which from their comments related to a problem with creating the tags. Moreover, the terms “ineffective” and “innovative” were used by a majority of the students. The term “ineffective” related to the amount of errors that occurred when tagging, whereas “innovative” was mostly characterised by a comment given by one student: “I think that the idea is very new and attractive. It can be very powerful”. In addition, the innovative aspect together with a comment like “it is really interesting and engrossing”, supports the findings of the usability evaluation, that although the prototype has to be improved, the students consider the tool to be useful.

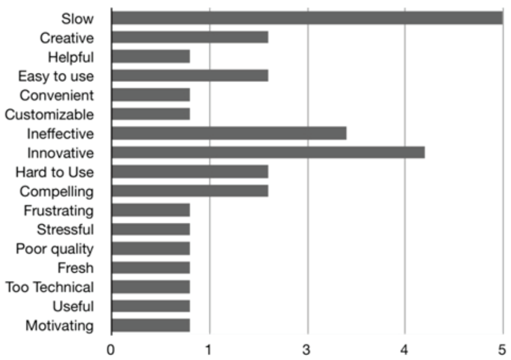

Figure 3. Number of times a term was chosen in rating the desirability

3.4.3 Results of the questionnaire for usefulness and satisfaction

From the analysis of the questionnaire (see Table 1), it can be observed that, although most of the students did not know what mobile learning was before taking part in the experiment (3) and had never used a mobile device for educational purposes (1), they think that the ContextBlogger has the potential to become a good learning tool as a supplement to construction issues (19). They also evaluated the ContextBlogger positively as the tool allows convenient access to discussions related to construction issues – anywhere and anytime (24) and also because it makes it easier to discuss construction issues with the instructor (13) and students (12). Moreover, they valued the capacity to provide instant access to construction issues regardless of their location (18). However, they considered that the system did not help in converting idle time into productive time with regard to construction issues (20), due to the slow response time of the system.

Table 1. Mean (M) and standard deviation (SD) for each of the questions in the questionnaire for usefulness and satisfaction

Item	Text	M	SD
1	I have already used my mobile phone for learning proposes before.	1,4	0,89
3	I know what mobile learning is.	1,8	0,84
12	ContextBlogger make it easier to discuss construction issues with other students	4	0,71
13	ContextBlogger make it easier to discuss construction issues with the instructor	4,2	0,84
18	ContextBlogger allow instant access to construction issues regardless of your location	4,4	0,55
19	ContextBlogger are useful as a supplement to construction issues	4,2	0,45
20	ContextBlogger are an effective learning aid or assistant for students with regard to construction issues	4,2	0,45
24	ContextBlogger can be used as a supplemental tool for any existing course	4,6	0,55

4. Providing MACE contents within Aloqa in a cloud-based approach

Aloqa (http://www.aloqa.com) is a service that proactively notifies the user of interesting Points Of Interest (POIs). It runs on wide range of smartphones, including iPhone, Blackberry and Android. With this tool one can easily get directions to events, places, buildings or other places of interests. Aloqa enables publishers to contribute channels, to which users can subscribe. Subscribers of a channel are notified of interesting content relative to their position. As the MACE federation features a rich metadata set including location metadata for many resources, integrating the MACE metadata into an Aloqa channel was a logical step to take. This feature was welcomed by many architects in MACE, e.g. when visiting a city, they have an interest in exploring its architectural assets.

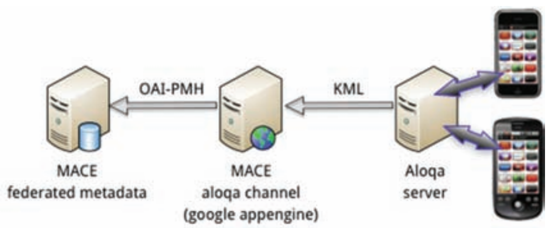

Figure 4. Architecture for providing a MACE feed for ALOQA

Creating such a channel for Aloqa was realised as a MACE spin-off project that builds on the services offered by the MACE federation. Figure 4 illustrates the architecture for this feed. Once per day, the MACE Aloqa channel harvests metadata updates from the MACE federation. It stores all metadata necessary for MACE in a database structure that is optimised to run geo-spatial queries. Realising this MACE channel as a Google App Engine (GAE) application has the following advantages:

- No maintenance. In contrast to hosting an application on a self-maintained server, this approach profits from the security of Google's infrastructure. Hence, there is no cost for keeping the service operational and secure.
- Automatic scaling is built in with App Engine. If this channel were to receive many subscribers, GAE would automatically replicate the application to the closest data centre.

A disadvantage of the GAE approach is that GQL, the Google query language, does not allow for joins and thus supports one table queries only. Furthermore, the duration of requests is limited. However, this is done on purpose, as it obliges developers to think about strategies on how to improve response times.

The Aloqa server accesses this GAE component through a KML feed. At regular times the Aloqa server sends a request including a geospatial bounding box. The MACE channel component responds to this request with a KML feed containing the MACE objects available in the requested area. Figure 5 shows sample screenshots of MACE contents in Aloqa.

5. Providing MACE contents in augmented reality browsers with the RADAR infrastructure

Augmented reality services are a special kind of location-based services that provide a computer-supported, extended reality by displaying relevant information in the user's environment. With the new generation of mobile devices and available reality browsers, there is for the first time an infrastructure that allows for the creation of augmented reality services without the need of a complex instrumentation and the development of respective interfaces. Thus, the plenitude of localised information can principally be made available to end users in different scenarios by means of augmented reality browsers, depending on the users' locations as well as their preferences and contexts. Yet, providing contents for these browsers is a difficult task that requires expert knowledge, and the content contribution process is different for each browser.

To conquer these problems, an open ecosystem that allows managing and aggregating arbitrary location-dependent multimedia from different sources like the Social and Semantic Web or digital repositories, and that can provide these contents for a variety of augmented reality browsers was developed within the project RADAR (see http://www.dfki.de/radar) (Resource Annotation and Delivery for Mobile Augmented Reality Services) initiated in 2010 at the German Research Center for Artificial Intelligence (DFKI).

5.1 The RADAR infrastructure

RADAR is an open infrastructure developed according to Web2.0 design paradigms. It realises a social hub for geocontents and allows

- managing, organising, and sharing geo-contents,
- publishing geocontents to various mobile augmented reality browsers,
- accessing and aggregating geocontents from various external sources, and
- visualising geocontents.

The RADAR infrastructure consists of the following main components: The RADAR Web Interface is an intuitive, web based GUI for comfortable contribution and management of arbitrary geocontents. It is based on DFKI's ALOE (see http://aloe-project.de) infrastructure and offers a plenitude of social media features. The RADAR Web Service realises a rich Web Service API and thus allows integrating RADAR contents and functionalities in different contexts and applications. It also allows for accessing a variety of external services that offer location-dependent information. This entails Social Web services such as Flickr, Foursquare, Panoramio, Twitter, and YouTube, but also Semantic Web data (via the integration of LinkedGeoData (see http://linkedgeodata.org). The RADAR Adapters allow pushing geocontents from the RADAR infrastructure to existing augmented reality browsers such as Layar, Wikitude or Junaio. The RADAR Mobile Client for Android based devices offers access to data published within RADAR, and also to the external services integrated in the RADAR Web Service. As the mobile client is also connected to the RADAR user management, users can maintain personal lists of favourites, connect to other users, etc. It also offers means to contribute geocontents.

5.2 Accessing MACE contents within RADAR

To integrate MACE in RADAR and thus allowing using MACE contents in all RADAR-supported scenarios, a connector for MACE was added in the RADAR Web Service.

5.3 MACE usage scenarios enabled by RADAR

With the integration into the RADAR infrastructure, MACE contents can now be used in several new scenarios. This allows for a variety of new informal learning scenarios, and it also provides new means to disseminate MACE and the MACE contents.

5.3.1 Providing MACE contents within augmented reality browsers

MACE contents can now be accessed in the augmented reality browsers Junaio, Layar, and Wikitude. In Figure 5, a sample content displayed in a reality mode within Layar is shown. By offering MACE in such contexts, a large amount of users can be made aware of the existence of MACE, as these browsers belong to the most popular applications for smartphones.

Figure 5. Screenshots of sample MACE contents displayed within ALOQA, in the reality view mode of Layar, and with the RADAR mobile client in a map mode

5.3.2 Mashups: Interactive map and timeline

The RADAR Web frontend offers an interactive map and timeline visualisation that allows for aggregating information from a variety of services that provide a search based on geoinformation. Users can freely choose a map section and select which services they want to include in their search. The RADAR Web Service is then accessing the selected services in parallel and displays the results on a map. Clicking on a single result on the map provides detailed information and further links to the respective detail pages, user profile pages, etc. A sample for an interactive map is shown in Figure 6. Furthermore, if a result provides information about its creation date, it is shown on an interactive timeline based on MIT's SIMILE project (http://simile.mit.edu).

Access to MACE and other services is also offered within in the RADAR mobile client. It offers a list mode, a map mode, and also a reality view mode in which results are displayed (see Figure 5).

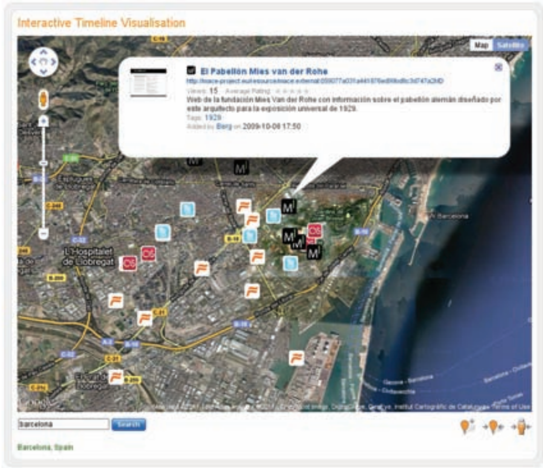

Figure 6. Interactive map visualisation of geocontents from MACE and further services within RADAR

6. Summary and outlook

The MACE service architecture allows offering the plenitude of MACE learning resources enriched with geoinformation in a variety of mobile scenarios. Blended learning scenarios with specifically designed mobile clients have been realised, as well as the integration of MACE contents in existing location-based services by using cloud-based approaches and the RADAR infrastructure. This enables the presentation of MACE to a wide audience by means of common standard tools available for any common mobile operating system.

As a next step, we aim at interactivity beyond the ability of standard location-based services that allow users to only consume information about geoinformation in their vicinity. A first step in this direction is typical Web 2.0 interaction possibilities such as tagging, rating, and commenting. Providing richer content, such as geo-located quizzes, forums, or polls, might be another way to support the learning process and to let the students reflect on the environment.

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