ADVANCED TECHNOLOGIES IN EDUCATION

DEVELOPING THE SCIENCE CLASSROOM OF THE FUTURE

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To Elpida, Eleytheria, Alexandra and Lydia-Georgia

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- 2004-2007 *CONNECT: Bridging the gap between formal and informal science Education through Advanced technologies* (Contract Number: 507844, FP6-ICT)
- 2007-2009 *EXPLOAR: Visualising the Invisible in Science Centres and Museums* (Contract Number: 2007-3617/001-001, Life Long Learning Programme)

I think the classroom can help. It is up to schools, and to all initiatives that can educate, including reliable Internet sites, to ensure that young people gradually acquire the correct understanding of scientific procedure. A most difficult task, because even knowledge transmitted by schools is often deposited in the memory like a sequence of miraculous episodes: Madame Curie who come home one evening and discovers radioactivity thanks to a mark on a sheet of paper, ...Galileo who sees a lamp swaying and suddenly discovers everything, even that the world rotates…It is the duty of a man of learning not only to do scrupulous research but also to present his knowledge effectively. Scientists sometimes still feel it's not dignified to take an interest in popularization, although masters in the field include Einstein and Heisenberg. But if we are to teach a nonmagical view of science, we cannot expect it to come from the mass media. The scientific community itself must construct it bit by bit in the collective awareness, starting with the young.

Uberto Eco, Turning Back the Clock, 2008

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SUMMARY

Information communication technology (ICT) nowadays provides innovative learning systems which although routinely available needs adjustment to real educational environments. Due to the complexity of the task an appropriate integration into everyday classrooms is an important global research challenges focusing on its utilization and effects in both, classroom and non-classroom settings. By rigorous collecting data on teaching methods, classroom characteristics and students' learning effects needs analysis by concentrating on selected variables that may determine effectiveness as well as teachers characteristics such as teachers' preparation and professional development. Therefore, the aim of the four presented research papers focuses on envision the science classroom of the future, by constructing a framework for improving current educational practices and learning processes in science and mathematics through the effective implementation of advanced technological tools and applications.

Overall this work presents a vision for the science classroom of the future: It will not be an island, a self-contained campus, a counter-world. The classroom of the future will be able to emit and absorb along different wavelengths, be immersed in contemporary culture, be open to the emotions, facts and news of its time. It will be permeated by society, but not unprotected: the relationship between school and society will be one of osmosis, where the pedagogical tools and applications act as a membrane and interface. For this purpose, four empirical studies were carried out in real school environments, based on the use of advanced educational systems.

(i) The first system under study is the COSMOS Portal, which is an educational repository that offers access to a network of robotic telescopes across the world. At the same time it offers access to more than 85,000 educational resources. The behaviour of the teachers who are using this system was mapped through the log files of the system database for a period of one year.

(ii) The second system, called Lab of Tomorrow, is a wearable device that allows high school students to use their every day life as the field where they will conduct sophisticated experiments and thus will deepen their understanding of the science concepts involved in the activities. The impact of the system on students learning and to the lesson profile was studied for a period of one school year.

(iii) The third system, called CONNECT, is also a wearable device that includes an advanced visualization system that augments additional information to the optical view of the user. The system is used in the framework of educational visits in science centres and museums

enriching the experiences of the visitors. The effectiveness of the system in supporting the students' conceptual change was studied in this case.

(iv) The fourth system, called EXPLOAR, evolved from the described CONNECT system to a much more user-friendly handheld device. Taking into account the school curriculum we have designed a series of scenarios of use of these tools. The scenarios of use include classroom activities, field trips in science centres and museums, informal learning activities, professional development opportunities and community building.

In all four studies, students' cognitive learning is analysed as well as selected teachers' tasks on the job. By applying different assessment methods and tools (questionnaires, video captures of lessons, log files and web based data) we monitored the implementation procedure across different European countries. Our working hypothesis is that amending the traditional scientific methodology for experimentation with visualization applications and model building tools will help students to articulate their mental models, make better predictions, and reflect more effectively. Additionally, working to reconcile the gaps and inconsistencies within their mental models, system models, predictions and results, will provide the learners with a powerful, explicit representation of their misconceptions and a means to repair them. Additionally our aim is to support teachers' professional development. Apart from the purely technical training, in order for teachers to introduce ICT-enhanced learning methods into their everyday practice, they will have to perform a change in behaviour and to adapt a new culture and philosophy. The use of the new tools asks for systematic and detailed lesson planning procedures and use of student centred approaches. In our work we are demonstrating methods for involving teachers in this process but also tools to monitor this behavioural change.

1 Rational and Background: Improving educational practices in science education

1.1 Science Education Now: A renewed Pedagogy for the Future of Europe

The publication of the "Science Education Now: A renewed Pedagogy for the Future of Europe" report (Rocard, 2007) brought science education to the top of educational goals of Europe (following similar actions in the US; NRC, 2007). The authors argue that school science teaching needs to become more engaging, based on inquiry-based and problem-solving methods and designed to meet the interests of young people. According to the report, the origins of the alarming decline in young people's interest for key science studies and mathematics can be found, among other causes, in the old fashioned way science is taught at schools. Although the crucial role of positive contacts with science at early stage in the subsequent formation of attitudes toward science is identified (PISA, 2006), traditional formal science education too often stifles this interest and, therefore, may negatively interact with the development of adolescents' attitudes towards learning science.

More specifically, according to the report, the main priorities for the science education at school level are:

- A reversal of school science-teaching pedagogy from mainly deductive to inquiry-based (inductive) methods provides the means to increase interest in science.
- Improvements in science education should be brought about through the new forms of pedagogy: The introduction of the inquiry-based approaches in schools and the development of teachers' networks should actively be promoted and supported.
- Renewed school's science-teaching pedagogy based on IBSE provides increased opportunities for cooperation between actors in the formal and informal arenas.
- Specific attention should be given to raising the participation of girls in key school science subject, and to increasing their self-confidence in science.
- Teachers are key players in the renewal of science education. Among other methods, being part of a network allows them to improve the quality of their teaching and supports their motivation.

To begin shifting toward a more inquiry-oriented classroom, five essential features need specific consideration:

a) Learners engage in scientifically oriented questions.

b) Learners give priority to evidence in responding to questions.

c) Learners formulate explanations from evidence.

d) Learners connect explanations to scientific knowledge.

e) Learners communicate and justify explanations.

Ad a) Learners engage in scientifically oriented questions

Scientifically oriented questions centre on objects, organisms, and events in the natural world; they connect to the science concepts described in the school curriculum. They are questions that lend themselves to empirical investigation and lead to gathering and using data to develop explanations for scientific phenomena. Scientists recognize two primary kinds of scientific questions. Existence questions probe origins and include many why-questions: Why do objects fall toward Earth? Why do some rocks contain crystals? Why do humans have chambered hearts? Many why-questions cannot be addressed in science. In addition, there are causal and functional questions, which probe mechanisms and include most of the how-questions: How does sunlight help plants grow? How are crystals formed? Students often ask why-questions. In the context of school science, many of these questions can be changed into how questions and thus lend themselves to scientific inquiry. Such change narrows and sharpens the inquiry and contributes to its being scientific. In the classroom, a question robust and fruitful enough to drive an inquiry generates a need to know in students, stimulating additional questions of how and why a phenomenon occurs. The initial question may originate from the learner, the teacher, the instructional materials, the World Wide Web, some other source, or some combination. The teacher plays a critical role in guiding the identification of questions, particularly when they come from students. Fruitful inquiries evolve from questions that are meaningful and relevant to students, but they also must be answerable by student observations and the scientific knowledge they obtain from reliable sources. The knowledge and procedures students use to answer the questions must be accessible and manageable, as well as appropriate to the students' developmental level. Skilful teachers help students focus their questions so that they can experience both interesting and productive investigations.

Ad b) Learner give priority to evidence in responding to questions

Science distinguishes itself from other ways of knowing through the use of empirical evidence as the basis for explanations about how the natural world works. Scientists concentrate on getting accurate data from observations of phenomena. They obtain evidence from observations and measurements taken in natural settings such as oceans, or in contrived settings such as laboratories. They use their senses; instruments, such as telescopes, microscopes or accelerators, to enhance their senses; and instruments that measure characteristics that humans cannot sense, such as magnetic fields. In some instances, scientists can control conditions to obtain their evidence; in other instances, they cannot control the conditions since control would distort the phenomena, so they gather data over a wide range of naturally occurring conditions and over a long enough period of time so that they can infer what the influence of different factors might be. The accuracy of the evidence gathered is verified by checking measurements, repeating the observations, or gathering different kinds of data related to the same phenomena. The evidence is subject to questioning and further investigation. In their classroom inquiries, students use evidence to develop explanations for scientific phenomena. They observe plants, animals, and rocks and carefully describe their characteristics. They take measurements of temperature, distance, and time and carefully record them. They observe chemical reactions and moon phases, and chart their progress.

Ad c) Learner formulate explanations from evidence

Although similar to the previous feature, this aspect of inquiry emphasizes the path from evidence to explanation, rather than the criteria for and characteristics of the evidence. Scientific explanations are based on reason. They provide causes for effects and establish relationships based on evidence and logical argument. They must be consistent with experimental and observational evidence about nature. They respect rules of evidence, are open to criticism, and require the use of various cognitive processes generally associated with science— for example, classification, analysis, inference, and prediction—and general processes such as critical reasoning and logic. Explanations are ways to learn about what is unfamiliar by relating what is observed to what is already known. So explanations go beyond current knowledge and propose new understanding. For science, this means building on the existing knowledge base. For students, this means building new ideas on their current understandings. In both cases, the result is proposed new knowledge. For example, students may use observational and other evidence to propose an explanation for the phases of the moon, for why plants die under certain conditions and thrive in others, and for the relationship of diet to health.

Ad d) Learners connect explanations to scientific knowledge

Evaluation, and possible elimination or revision of explanations, is one feature that distinguishes scientific inquiry from other forms of inquiry and subsequent explanations. One can ask questions such as: "Does the evidence support the proposed explanation?", "Does the explanation adequately answer the questions?", "Are there any apparent biases or flaws in the reasoning connecting evidence and explanation?", and "Can other reasonable explanations be derived from the evidence?" Alternative explanations may be reviewed as students engage in dialogues, compare results, or check their results with those proposed by the teacher or instructional materials. An essential component of this characteristic is ensuring that students make the connection between their results and scientific knowledge appropriate in their level of development. That is, student explanations should ultimately be consistent with currently accepted scientific knowledge.

Ad e) Learners communicate and justify explanations

Scientists communicate their explanations in such a way that their results can be reproduced. This requires clear articulation of the question, procedures, evidence, and proposed explanation and a review of alternative explanations. It provides for further sceptical review and the opportunity for other scientists to use the explanation in work on new questions. Having students share their explanations provides others the opportunity to ask questions, examine evidence, identify faulty reasoning, point out statements that go beyond the evidence, and suggest alternative explanations for the same observations. Sharing explanations can bring into question or fortify the connections students have made among the evidence, existing scientific knowledge, and their proposed explanations. As a result, students can resolve contradictions and solidify an empirically based argument.

This approach does not culminate with the characterization of inquiry learning and teaching outlined in this section. It is also necessary to characterize the learning environments (in and outside school) that provide suitable contexts and opportunities for ISBE (for learners and for teachers) and the professional development programs that can support the desired change in teachers' practice towards ISBE. Kinchin (2004) pointed out that the tension created between objectivism (the objective teacher-centred pedagogy) and constructivism (the constructive and student-centred pedagogy) represents a crucial classroom issue to influence teaching and learning. The TIMSS (Third International Mathematics and Science Study) 2003 International Science Report (Martin et al., 2004) specifically documented that internationally, the three most predominant activities accounting for 57 percent of class time were teacher lecture (24%), teacher guided student practice (19%), and students working on problems on their own (14%) in science classes in the European countries participating in the study. In practice it appears that the current science classroom learning environment is often a mixture of divergent pedagogies and diverse students' orientations or preferences (Chang & Tsai, 2005; Chang, Hsiao, & Barufaldi, 2006). The fact is that there is a major mismatch between opportunity and action in most education systems today. It revolves around what is meant by "science education," a term that is incorrectly defined in current usage. Rather than learning how to think scientifically, students are generally being told about science and asked to remember facts (Alberts, 2009). This disturbing situation must be corrected if science education is to have any hope of taking its proper place as an essential part of the education of students everywhere.

In addition to the aforementioned issues, science learning environment (classroom and lab) seems to have not gone through any significant changes for the past decades. Recent research on learning and instruction has substantially advanced our understanding of the processes of knowledge and skill acquisition (Bybee, 2008). However, school practices have not been innovated and improved in ways that reflect this progress in the development of a theory of learning from instruction. School practices in a realistic sense are cantered on school learning environment. It is generally recognized among practitioners that our school science learning environment has neither been innovated nor reformed to reflect these new knowledge on learning and teaching. Moreover, modern technologies beyond just the use of computers and internet in the school have not fully integrated/incorporated in current science learning environment.

According to the recent report "Science Education in Europe: Critical Reflections" (Osborn & Dillon, 2008) the deeper problem in science education is one of fundamental purpose. Schools, the authors argue, have never provided a satisfactory education in sciences for the majority. Now the evidence is that it is failing in its original purpose, to provide a route into science for future scientists. The challenge therefore, is to re imagine science education: to consider how it can be made fit for the modern world and how it can meet the needs of all students; those who will go on to work in scientific and technical subjects, and those who will not (Kali & Linn, 2009).

Most of the recent calls for educational reform focus on the need for curricula emphasizing conceptual learning that is integrated across traditional subject areas (Osborn & Dillon , 2008). Interdisciplinary instruction links various content areas and is organized around questions, themes, problems, or projects rather than along traditional subject-matter boundaries. Such instruction is said to be responsive to children's curiosity and questions about real life and to result in productive learning and positive attitudes toward school and teachers. Classroom strategies for learning become more student-centred, with learning of content increasingly embedded in real-world contexts, separation between academic curriculum areas becomes less defined. Problem-oriented learning that is connected to real-world problems draws from many disciplines to find solutions. When a powerful idea or relevant problem is presented in a learning context, students are motivated to collaborate, explore the idea, and find solutions. In their quest, it becomes apparent that

- Communication skills are necessary.
- Historical perspective may provide clues to the exploration or solutions.
- Mathematical principles and skills can help in measuring, graphing, calculating, and analyzing the problem.
- Technology tools can assist in researching the problem, collecting and organizing information, and presenting results.

Learning through such interdisciplinary and student-directed learning activities was proved effective and long lasting. New learning environments must provide students with experiences in which they draw upon knowledge from several disciplines, apply a variety of strategies to get at the intended learning, and choose from a rich array of learning tools to examine, publish, illustrate, and communicate their results. Perhaps our greatest challenge in applying interdisciplinary learning exists at the secondary grade levels. Many high schools have yet to adjust their schedules, strategies, or educational philosophies to accommodate the need to connect learning to real-world contexts and problems. Information technology cuts across all disciplines. It is a powerful aid to addressing real-world multidisciplinary problems. The ability to access and store digitized information allows the student to research, collect, and share on a level hitherto unparalleled. Collaboration and consultation with other students and experts is fast becoming an everyday experience. Increasingly powerful computers provide students with real-world problem-solving tools. They help students overcome handicaps, choose among learning strategies, perceive and create new relationships among subjects, and demonstrate their knowledge in words, pictures, moving images, and sound. The experience of these changes allows us to preconceive the high school learning environment where disciplines cross-pollinate and students' learning is truly integrated.

1.2 Developing the Science Classroom of the Future

In this framework, the science classroom of the future should provide more challenging, authentic and higher-order learning experiences, more opportunities for students to participate into scientific practices and task embedded in social interaction using the discourse of science and work with scientific representations and tools. It should enrich and transform the students' concepts and initial ideas. These ideas could be both resources and barriers to emerging ideas. The science classroom of the future should offer opportunities for teaching tailored to the students' particular needs while it should provide continuous measures of competence, integral to the learning process that can help teachers work more effectively with individuals and leave a record of competence that is compelling to students. In the framework of our work we are presenting how advanced technological solutions like the COSMOS Network of Robotic telescopes, the Lab of Tomorrow system, the CONNECT and the EXPLOAR devices could support the development of effective links between formal (school, lab) and informal (science centres, museums, home) learning settings. The systems that we have studied in the framework of the current research bring into the classroom activities that are based on real-world problems and involve students in finding their own problems, testing ideas, receiving feedback, and working collaboratively with other students or practitioners beyond the school classroom, provide tools and scaffolds that enhance learning, support thinking and problem solving, model activities and guide practice, represent data in different ways, and are part of a coherent and systemic educational approach. Additionally these systems give students and teachers more opportunities, including those where students evaluate the quality of their own thinking and products, for feedback, reflection, and revision give students and teachers the opportunity to interact with working scientists, receive feedback from multiple sources including their peers and experienced cognitive tutors, and coach in areas where improvement is needed. Finally the use of these systems facilitate the development of local and global communities where teachers, parents, students, practicing scientists, and other interested community people are included in order to expand the learning environment beyond the school walls, and expand opportunities for teachers' professional development which includes helping teachers to think differently about learners and learning, reduces the barriers between students and teachers as learners, creates new partnerships among students and parents, and expands communities of learners that support ongoing communication and professional development of teachers.

The objective of the educational scenarios which we are presenting is not to detail blueprints of an unalterable future, but instead to show the range of possibilities enabled by emerging interactive media and the consequences – desirable and undesirable – that may follow from their application at high school settings. Such visions suggest decisions that researchers should make today to explore the potential of these technologies while minimizing unintended and negative outcomes of their use.

2 Methods for involving teachers

As mentioned before, teachers have a key role to play in the implementation of innovation in the classroom. In order for them to fully realize the potential of new technologies, the design of the new tools has to address all potential fears and negative preconceptions related to the use of technology adequately and assist them in every step of the process. There is plenty of evidence pointing to the difficulty of incentivising and empowering teachers to engage in innovation, especially in tightly accountable systems based on performance targets. In education there is no shortage of energy and expertise, and certainly no lack of commitment or moral purpose amongst teachers. How could we support them, and give them the creative space and incentives they need to be innovative? What sort of interventions could both release professional imagination, whilst encouraging work that is disciplined and system relevant? How can the system learn from the resultant innovation and its process characteristics so that these can be taken to scale? How can busy, performance-driven teachers become aware of approaches and techniques which are emerging in other sectors - private and voluntary, as well as across public services more widely? It is enormously difficult in practice to be fully alert to developments and methods outside one’s “zone of operation” (and sometimes even within it) which offer improvement potential. Some school leaders do manage to scan other horizons for ideas with transfer potential. How far can this be done on their behalf, to shortcut the investment of time, and also optimize the scope for adaptation? As it is analytically described in our study there are two key points where we need to focus our full attention:

- **Using ICT enhanced methods:** Albeit very effective, ICT methods in education constitute a major paradigm shift for teachers: they need to acquire new skills, abandon long standing practices and move away from their professional “comfort zone”, therefore exposing them to perceived, or real, risks.
- **Assisting behavioural change:** apart from the purely technical training, in order for teachers to introduce ICT-enhanced learning methods into their everyday routine, they will have to perform a change in behaviour and to adapt a new culture and philosophy. The use of the new tools asks for systematic and detailed lesson planning procedures and use of student centred approaches.

In the following paragraphs we are describing the framework that was adopted in all cases for the effective introduction of the teachers to the use of these advanced technological tools.

2.1 A new role for the teachers

When talking about the use of ICT in the classroom, one should consider the specific conditions that can act as constraints in the diffusion and successful implementation of such an innovation. These conditions are related to the existing curriculum, managerial issues, range of resources available, level of competency and attitude of the teacher. In fact, the teacher is a key player in the implementation of the innovation. At the centre of effective use of instructional technology is the teacher. For students to become comfortable and effective users of various technologies, teachers must be able to make wise, informed decisions about technology. All teachers should be confident in applying technology when and where appropriate.

As quoted in McCombs & Miller (2007), the more powerful technology becomes the more indispensable good teachers are expected. From this point of view, teachers who are pedagogical design experts and facilitators of learning are needed. Technology may change some of the traditional teacher roles but it will also require them to engage more powerful roles - roles that include not only using technology appropriately that opens new pathways to learning not previously available but also require teachers to find ways to build on meaning, purpose, connections and relationships to the larger world and community outside the school building. The use of the COSMOS Portal supports teachers in the design of educational activities that are based on well defined pedagogical approaches (e.g. Guided Research Model, Learning Cycle, Problem-Based Approach). Effective lesson planning is also necessary in the interdisciplinary approach of the Lab of Tomorrow system. The use of the system supports the effective introduction of Inquiry Based Approach in the science lessons.

According to our findings from the implementation and the use of the different technological tools the role of the teacher in the new technology-rich instructional paradigm involves the following

- becoming the creator of an effective external learning environment that stimulates the environment within the classroom,
- mentoring and counselling to ensure that learners are encouraged to pursue their learning in an appropriate and meaningful direction using approaches best suited to them as individuals,
- facilitating students' inquiry, guiding student work and offering individual help,
- coaching, observing students, offering hints and reminders, providing feedback, scaffolding and fading, modelling.

However, there are a number of teacher-related factors that should be carefully considered so that appropriate support and professional development opportunities are provided. These teacher-related factors that can act as barriers include the following:

- Established patterns and limited exposure to new models. This issue was mainly studies in the framework of the COSMOS related activities – teachers had to design educational activities according to specific pedagogical models – and during the implementation of the Lab of Tomorrow activities where their approaches and teaching methods were compared to the Inquiry Based Approach. According to Collis (Collis, 1996), teachers may have developed patterns and styles of teaching and students interaction that fit their own circumstances and can be managed. Previous practice provides them security. Many prefer replicating traditional chalk and talk instruction and "safe", teacher-led and controlled learning activities. Changing what they think as appropriate pedagogy for the learners, themselves and their subject area may be difficult. This can be even harder when teachers act in isolation from one another and are not exposed to innovative models of learning.
- Accessing technology for lesson preparation but also for instructional purposes plays a significant role. The availability and operability of technologies influences the extent to which they are used. The extended data from the use of COSMOS Portal for lesson preparation demonstrate in a unique way the how significant is for lesson planning the easy access to high quality content. We have to note here that the content organisation according to the school curriculum was a very crucial factor that supported the work of the teachers.
- Teachers' workload and lack of flexibility in time and in the curriculum are also considerable constraints.
- The school's culture.

Drawing from various interpretations, Stoll and Fink (1996) define school culture as follows; various formal and informal elements, the beliefs that colleagues share, the dominant values and the school vision as well as the organisational rules and policies that regulate the life of the school. We should not forget that the teacher is part of a whole, is a member of an organisation with which he/she interacts. If a teacher works in isolation from peers, without collegial support and in a stagnant environment, he/she is likely to be influenced by it and remain static. On the other hand, an organisational culture that is characterised by teacher collegiality and formal or informal collaborative work, both supports and facilitates the development of the organisation's members. Teachers working in an environment where they feel safe, give and receive support from their peers and/or from the head, exchange ideas and innovative practices and share the same values, are likely to respond positively to an innovation and embrace it.

What teachers need in order to respond to their new role are skills in ICT which can be classified into a range of competences. These competences act as a useful framework for teacher professional development and should be perceived as integrated elements of a teacher's professional role and activities.

The "Pathway to High Quality Science Teaching" Report (Sotiriou & Bogner, 2005) lists seven elements

- positive attitudes to ICT,
- understanding of the educational potential of ICT,
- ability to use ICT effectively in the curriculum,
- ability to manage ICT use in the classroom,
- ability to evaluate ICT use,
- ability to ensure differentiation and progression,
- technical capability to use an appropriate range of ICT resources and to update these skills.

In order to develop these skills and overcome the barriers mentioned above, teachers need

- sufficient professional development opportunities in order to (1) learn how technology works and how it is integrated into the curriculum, (2) develop new skills, and (3) change attitudes, and
- support both on pedagogical and on technological issues in order to sustain the use of new technologies in the instruction and to help teachers respond to the demands of their new multifaceted role.

However, changing roles and adopting a new model of instruction which involves the use of ICT is a lengthy process. Teachers go through certain phases before they fully adopt and commit themselves to using ICTs for instructional purposes. Riel and Fulton (Riel & Fulton, 1998) adopt the stages that describe teacher's change in relation to technology intensive environments or projects, i.e., the entry level, the adoption level, the adaptation level and the appropriation level, identified by ACOT (Apple Classrooms of Tomorrow research project) researchers.

- **Entry level:** much frustration and anxiety, with a focus on replicating traditional instruction and learning activities.

- **Adoption level:** beginning to move from concern with connecting the computers to using them, but with much of the attention on how they can support established instructional formats and teacher presented lectures and presentations.
- **Adaptation level:** greater focus on ways student involvement may change, and teaching style may differ (e.g. giving students more responsibility, encouraging students to use and create activity modules similar to those the teachers are creating).
- **Appropriation level:** new instructional patterns start to emerge building around interdisciplinary project based approaches, more reflection on teaching and recognizing the need for alternate models of assessment and classroom structuring.

Only when teachers adopt innovation and commit themselves to using technology for instructional purposes, can we ensure that students will be prepared for the challenges they will face in the future. Simply providing sufficient access to technology for teaching and learning is not enough. The preparation of new teachers should be improved, including their knowledge of how to use technology for effective teaching and learning; the quantity, quality and coherence of technology-focused activities aimed at the professional development of teachers should be increased; and the instructional support available to teachers who use technology should be improved.

2.2 Training for teachers to use ICT enhanced educational methods

Seeking maximum efficiency in training teachers, we resorted to a blended learning delivery model. This is arguably the optimal model for professional training since it allows for flexibility without sacrificing efficiency. The training program for teachers encompassed three components:

- **Workshops and Summer Schools:** A number of training workshops were carried out in order to familiarize teachers with the necessary computer skills that the teachers needed to use the systems, the structure and functionalities of the tools. Furthermore, the workshops elaborated on the proposed scenarios and gave the basic guidelines for teachers to prepare their own scenarios and adopt the use of the tools in their own classrooms in order to meet their own needs.
- **E-learning modules:** After the initial training workshops, teachers had access to a number of e-learning modules (web seminars, digital material, documentation) that allowed them for dive deeply into the material briefly presented during the workshops and enhance their relevant skill set. Furthermore, community building tools that helped teachers community

development with one another and establish self confidence in the use of the newly presented technologies and methods. Developing effective communities of practice is one of the most prominent ways of introducing teachers to new technologies.

- **Twinning:** In all of the cases under study we have involved schools who participate in the activities into an exchange to present their achievements and discuss the challenges. This was done in a twinning approach of two schools with each other. The twinning process had a virtual component and – in some cases, also a real component of face-to-face meetings.

2.3 Assisting behavioural change and professional development of teachers

Asking teachers to follow advanced ICT methods in their everyday teaching practice constitutes a major behavioural change and at the same a significant development opportunity for them. The task at hand is to manage this change in a uniform way, allowing teachers to realize the potential of the opportunity offered by the tools that are studied in this work, take ownership of their contribution and maximize the output for both the project and themselves.

In a review paper (Lawson & Price, 2003), McKinsey management experts identify four key prerequisites for accelerating and establishing change:

- **A purpose to believe in:** “I will change if I believe I should” The first, and most important, condition for change is identifying a purpose to believe in. In our case, we must persuade teachers of the importance of scientific literature in terms of social value, importance to their students and personal achievement through learning and teaching these important subjects. We must carefully craft a “change story” underlining the benefits that the project can offer to all the involved actors. Furthermore, we must cultivate a sense of community, making the teacher feel part of a cohesive multi-national team. This sense of belonging was proved very important for motivating teachers and asking them to take then next, possibly “painful” steps, of learning new skills.
- **Reinforcement systems:** “I will change if I have something to win”. From a pure Skinner behaviouristic point of view, changing is only possible if formal and informal conditioning mechanisms are in place. These mechanisms can reinforce the new behaviour, penalize the old one or, preferably do both. In our case, we have used informal reinforcement patterns in order to make teachers commit more to implemented activities. A short list of such

methods could include competitions, challenges, promoting the best teacher created content, offering summer schools as rewards, etc.

- **The skills required for change:** “I will change if I have the right skills”. A change is only possible if all the involved actors have the right set of skills. In the case of the scenarios implemented, our training program was designed in such a way that teachers acquire all the skills they needed, both technical and pedagogical.
- **Consistent role models:** “I will change if other people change”. A number of “change champions” will need to be established, acting as role models for the community of teachers. These very active and competent teachers will be a proof of concept for their colleagues that the change is indeed feasible, acceptable and beneficial for them. To achieve that we had to identify the high flyers among the participating teachers and pay special attention into motivating them, supporting and encouraging them.

All four aspects were specifically addressed in each of the participating schools. Additionally we have collaborated closely with teachers to develop a set of support services which help teachers to implement the necessary changes in their settings.

2.4 Creation of learning communities

Advocates of the use of ICTs in the classroom claim that universal access to the Internet mainly will (i) expand the resources for teaching and learning in schools and classrooms, (ii) provide more challenging, authentic and higher-order learning experiences for students.

Technology can support learning in five ways (Bransford, Brown & Cocking 1999)

- **bring into the classroom activities that are based on real-world problems** and that involves students in finding their own problems, testing ideas, receiving feedback, and working collaboratively with other students or practitioners beyond the school classroom, provide tools and scaffolds that enhance learning, support thinking and problem solving, model activities and guide practice, represent data in different ways, and are part of a coherent and systemic educational approach,
- **give students and teachers more opportunities**, including those where students evaluate the quality of their own thinking and products, for feedback, reflection, and revision,
- **give students and teachers the opportunity to interact with working scientists**, receive feedback from multiple sources including their peers and experienced cognitive tutors, and coach in areas where improvement is needed,

- **build local and global communities** where teachers, administrators, parents, students, practicing scientists, and other interested community people are included in order to expand the learning environment beyond the school walls, and
- **expand opportunities for teachers' education** which includes helping teachers to think differently about learners and learning, reduces the barriers between students and teachers as learners, creates new partnerships among students and parents, and expands communities of learners that support ongoing communication and professional development of teachers.

One of the most quoted reasons why ICT should be integrated into teaching is that it contributes to enhance the quality of teaching and learning. One aspiration is the more effective achievement of existing educational goals. Another aspiration is that ICT should act to liberate learners. The central issue is to empower the students' autonomy over the pace and content of his/her own learning. Choosing to use ICTs in the classroom demands changes in the way the instruction is organised. Teachers' attitudinal changes concerning classroom practice play a fundamental role in realising the potential of ICTs in education.

3 ICT-based innovation for quality learning and teaching

The main missing link in a science learning process usually is that students do not learn sufficiently through experience but through a systemic model based approach, which should be the culmination of learning efforts and not the initiation. A particularly disturbing phenomenon is that students fail to see the interconnections between closely linked phenomena or fail to understand the links of their knowledge to everyday applications. The educational experiences should be authentic and they have to encourage students to become active learners, discover and construct knowledge (Scharfenberg et al. 2007) Authentic educational experiences are those that reflect real life, which is multifaceted rather than divided into neat subject-matter packages.

The implementation of a series of innovations and their systematic evaluation will highlight and promote best practices in expanding the limits of the school science instruction. Such a process will help to chart the course into the future. By building on the best of current practice, our approach aims to take us beyond the constraints of present structures of schooling toward a shared vision of excellence. We are presenting a series of exemplary teaching practices, resources and applications that provide teachers and students with experiences that enable them to achieve scientific literacy, criteria for assessing and analysing students' attainments in science and learning opportunities that school programmes afford.

This could be the window onto live scientific experiments and phenomena, ongoing research, and the personalities and stories of working scientists across Europe.

The science classroom of the future features a collection of interconnected e-systems and Web-enabled services to facilitate teaching, learning and assessment. All these new systems will require interfacing with key existing legacy systems that are characterized by different organizational structures. Creating an IT infrastructure plan for the school of the future isn't just about plugging in the latest and greatest — it's about balancing competing forces.

According to our view, as it is described in this study, three complementary interfaces will shape the technological infrastructure of the science classroom of the future:

- **The familiar "world to the desk top" interface**, providing access to distant experts and archives, enabling collaborations, mentoring relationships, and virtual communities-of practice. This interface is evolving through initiatives such as Web 2.0. The work will focus on the support of learning communities where teachers and learners are helping each other, or work together on certain problems. In order to monitor, analyze and support those learning communities we need to implement tools which capture usage and interaction. We also need personal and digital agents that help to build up a learning context based on content in order to support teachers and students.
- **Interfaces for "ubiquitous computing",** in which portable wireless devices infuse virtual resources as we move through the real world (Druin, 2009). The early stages of "augmented reality" interfaces are characterized by research on the role of "smart objects" and "intelligent contexts" in learning and doing. Those interfaces are intended to provide the freedom to learn "on site" – get into a real problem context and learn on virtual data. Therefore we need mixed reality cross platform devices, to create interfaces that seem to inhabit the users' environment. Those tools should be seamlessly integrated into the users' world. The interfaces should be light weight and least intrusive. The users have to be able to interact within their augmented environment in a most possible intuitive way. In order to create such a ubiquitous environment interfaces should be available at any time and any place where the user can be. Thus one has to build on mobile devices and visible (e.g. QR-Tags, Semacode) and ubiquitous tracking techniques, such as GPS or NFC (near field communication), inertial tracking and a complementary computer vision tracking. One major aspect of those devices will be interactivity that allows users intuitive interaction with real and virtual elements of their augmented world. Also personal data security and privacy will be taken into account. Furthermore, there has to be an underlying knowledge and context system, in order to make objects smart and to

allow for better interactivity. The context system also provides learner analysis and evaluation functionality.

- **Immersive and multi-user virtual environments interfaces**, in which users and participants' avatars interact with computer based agents and digital artifacts in virtual contexts. The initial stages of studies on shared virtual environments are characterized by advances in Internet games and work in virtual and augmented reality. In order to implement "Virtual Labs" and multi user environments we demand a VR interface, an underlying context system, a high bandwidth network communication, as well as a hypermedia database. The most important part of a virtual environment is the interface through which users are able to enter the virtual world. Immersion plays a key role, thus all senses need to be stimulated properly. Moreover, it is fundamental for the effect of immersion that the system should behave in a way the user expects it to behave. This is, interaction has to be intuitive, user tracking should be accurate, this is, the system output should be realistic if necessary.

In this framework, four systems were studied in detail: The **COSMOS Portal** (a "world to the desk top" interface), **the Lab of Tomorrow system** (interfaces for "ubiquitous computing" that is based on wearable technology), **the CONNECT** and **the EXPLOAR systems** (two immersive and multi-user virtual environment interfaces that are also based on augmented reality applications). The outcomes of the research effort are presented in four papers.

The **first paper** analyses the COSMOS Portal (www.cosmosportal.eu) (Sotiriou, 2008), an advanced Educational Repository for Science Teaching. It has been designed to facilitate science teachers' search, retrieval, access and use of both scientific and educational resources. It introduces teachers to an innovative methodology for designing, expressing and representing educational practices in a commonly understandable way through the use of user-friendly authoring tools. COSMOS materials include images, videos, animations, simulations, lesson plans, students projects and teachers guides.

The COSMOS Portal is in operation for one year and includes more than 85,000 educational objects while it is supported from a very active community of 1500 science teachers from many European Countries. The content of the COSMOS Portal is available in English, German, Greek, Finnish, Swedish and Turkish. The aim of our work was a) to design and deploy a systematic approach for measuring the effectiveness of the COSMOS Portal educational design and b) to prove the significant contribution of the COSMOS Portal to the introduction to the teachers' communities of a culture of sharing and re-use of educational resources. The data from the COSMOS Portal use were collected through the Google

Analytics monitoring system. For the analysis of the data and the mapping of the COSMOS Portal users behaviour we have use as reference the research work of Ochoa & Duval (2009), who are presenting an quantitative analysis of the size and contributor base growth of educational repositories and the research work of Huberman et al. (1998) who described with the "law of surfing" a common pattern of surfing behaviour of the users of digital repositories (Eq. 1).

$$P(L) = \sqrt{\frac{\lambda}{2\pi L^3}} \exp\left(\frac{-\lambda(L-\mu)^2}{2\mu^2 L}\right) \quad (1)$$

According to the findings the exponential growth of the contributors to the COSMOS Portal is followed from an exponential growth for the uploaded content. The COSMOS users are contributing numerous educational materials (about 50 learning objects per contributor) while they are visiting the COSMOS Portal again and again. In order to study further these very promising results a series of additional parameters were examined during the initial operation of the COSMOS Portal. These parameters comprises the total number of the COSMOS portal visits; all, new, and returning unique visits; page-views; pages/visit; and a series of parameters that could demonstrate the visitor loyalty like the average time on site per visit; the depth of each single visit (number of pages visited). According to our data a significant behavioural change is identified as the returning users are using more and more frequently the COSMOS Portal in the after-school hours, namely during the preparation of the lessons as it was expected from the educational design of the COSMOS Portal. Additionally we are presenting the results from a quantitative analysis in terms of the power law distribution, parameterized as $P(L) \propto L^{-3/2}$, where $P(L)dL$ is the probability for a web-page to be visited by L and dL users. Although its new users follow a typical surfing pattern, returning users outperform this pattern, "foraging" frequently, deeper and longer for the science education content offered by the portal.

The **second study** monitored the use of the Lab of Tomorrow system (www.ea.gr/ep/laboftomorrow) (Orfanakis et al., 2005, Arvanitis et al., 2009) in high school science classrooms in Germany, Austria, Greece and Italy. The specific system provides more challenging, authentic and higher-order learning experiences, more opportunities for students to participate into scientific practices and task embedded in social interaction using the discourse of science and work with scientific representations and tools. It enriches and transforms the students' concepts and initial ideas. Furthermore the use of the system offers opportunities for teaching tailored to the students' particular needs while it provides continuous measures of competence, integral to the learning process that can help teachers work more effectively with individuals and leave a record of competence that is compelling to students.

Wearable computers and intelligent sensors were embedded in everyday objects (e.g. t-shirts, balls) and used during students' usual activities. The sensors, which called "axions" were capable to record the acceleration of the body (or of the ball), the temperature of the body and the heart beat rate or the wearer. The recorded data were utilised by a specially designed user Interface in order to graph trends and patterns and investigate the laws of physics. The students had the opportunity to collect data from a variety of sensors, compare their measurements and design new experimental activities on their own. In this way, teaching offers as many links as possible between the natural sciences and daily life. In order to obtain the maximum of flexibility regarding both the lesson plans that were designed to support the system's introduction in the schools and the students learning processes, the system was designed by adopting a modular approach: Small devices collected data during students' experimental activities. Therefore, students were enabled to easily quantify these observations, identify schemes or patterns and derive hypotheses and theories. A series of lessons, designed and implemented in real school environments, were full in line with the science curricula of the participating classrooms while they were provide the necessary links with everyday activities of the students. When teachers and students were familiarized with the approach, they were asked to design and develop their own experiments using the Lab of Tomorrow system and use different activities as a mean of experimentation. In the framework of the implementation of the proposed activities the lessons were classified in three different categories, according to the different phases of the classroom implementation: (i) Lesson type A: Introductory lesson, in which the teacher presented and explained the functionalities the Lab of Tomorrow system. (ii) Lesson type B: Lesson with simple experiments, in which students performed experiments with the Lab of Tomorrow system initiated by the teacher, based on the scenarios developed by the research team. (iii) Lesson type C: Lesson with complex experiments, in which students performed experiments with the Lab of Tomorrow system initiated by them. In the presented study, our results from different classrooms in different countries that have been involved in the Lab of Tomorrow activities during a whole school year, demonstrate that there is significant improvement of the learning outcomes for the students in all cases in both physics and mathematics. Additionally the outcomes of the extended lesson video capturing study are also demonstrate that the Lab of Tomorrow system is offering a great opportunity to the teachers to adopt inquiry based methods in their lessons, that have proved their efficacy in increasing students' interest and attainments level while at the same time stimulating teacher motivation. Through the analysis of 200 lesson hours we mapped the science lessons' profile with the use of the Lab of Tomorrow system and demonstrated that a) it supports a reversal of science instruction from mainly deductive to inquiry based approach, b) the lessons with the use of the system include all the essential features of inquiry and c) the use of the system effectively introduces the teachers in the adaptation of inquiry based methods that simulate the scientific methodology in the school classroom or laboratory.

The **third paper** describes and analyses the educational use of the CONNECT wearable system (www.ea.gr/ep/connect) (Sotiriou et al., 2006). The CONNECT system can assist users to better contextualize and reinforce their learning in school and in other settings where people learn (i.e. science centres, science parks and exhibitions). The CONNECT concept and associated technologies encourage users to visit science centres and perform experiments that are not possible in school. They can also build on these experiences back at school with visual augmentations that they are communicated through web-based streaming technology. The system offers unique opportunities to the science museum and the science centre visitor. A series of augmentations of physical phenomena, pictures, video and text are presented to his/her optical view explaining the physical laws and phenomena under investigation. Our study was realized in Greece, at the Eugenides Science Exhibition. 119 high school students (15-16 years old) took part in the study. Our findings suggest that the CONNECT approach, which focuses on the use of AR technology during a science center– school program, provides added value to science learning. We believe that our findings allow the presumption that this value added contribution of the CONNECT approach derives from two central factors: (a) increased student experimentation and (b) increased student interest. In other words, we argue that, under the conditions identified and described above, the AR technology can function to provide a stronger context for student investigations and for the development of student interest than the traditional field trip. We suggest that the AR-related features that are responsible for these differences include the opportunity for students to make more precise measurements, a deeper personal experience with the scientific phenomenon (as a result of increased experimentation), and AR graphic visualizations of the unseen but vital factors. Our data support the argument that learning involves (a) student knowledge gain, (b) increased student motivation and attitudes, and (c) improved student investigation skills. These three aspects were mentioned as the three basic ‘goals of learning’ by the participating science teachers and they also represent the ‘criteria of success’ for successful science center–school partnerships. In the framework of the study, the schools were able to devote more time to the first goal (knowledge gain). Owing to the authentic context of the exhibits and AR technology, the science center experience contributed a great deal to the achievement of the third goal (increased motivation and positive attitudes). In addition, by focusing on the achievement of the second goal (student investigation skills), via the AR-mediated visualizations and measurements, the proposed approach helped to provide a 'common agenda' for the student work in the two contexts. Combining school science with students' activities in a science center, as well as introducing advanced visualizations to a physical phenomenon, appears to make a difference.

The **fourth paper** presents the educational use of the EXPLOAR handheld device (www.ea.gr/ep/exploar) which consists the evolution of the CONNECT system. Building on the findings from our work with the CONNECT system in Greece we have tested the approach with the EXPLOAR system in Finland in the Heureka Science Center. 308 high school students and 182 teachers took part in the study. Our study has demonstrated encouraging empirical effects related to intrinsic motivation and cognitive learning of students. The implementation of AR technology in the context of the "Hot Air Balloon" exhibit unveiled also encouraging results: While the high achievers again did best in the post-knowledge test, low achievers again were clearly catching up with the others. The difference to between the treatment and the control group was clear. It seems like that visualising a very theoretical scientific phenomenon increased the individual understanding substantially especially for those students who otherwise had severe difficulties. This is an essential result which needs further analysis. The "new educational model & paradigms" was monitored for 182 teachers. The main focus, however, pointed to a feed-back of in-service teachers and teacher students since they act as key players in the use and acceptance of any new educational technology or curriculum renewal. The main objectives were to map the process from a teacher-controlled learning towards a student-orientated approach and to identify changes in roles and responsibilities of students and teachers.

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Statement of own contribution

This research work is based on the study of four advanced educational systems. Many researchers, technical experts and teachers were involved in their development. I have been involved in the initial design of all the four publications and I have followed closely their complete development.

More specifically, in the work presented in the first paper I had the responsibility for the educational design of the COSMOS Portal. For the analysis of the numerous statistical data (about 1500 registered users) and the development of the mathematical models to map their behaviour I collaborated closely G.Neofotistos (University of Crete). The final analysis of the findings and their integration was made with the collaboration of F.X.Bogner.

In the second paper I mainly designed Lab of Tomorrow system and completed its implementation. I have categorized and analyzed the video-lessons from the implementation as well as analysed the quantitative and qualitative findings.

In the framework of the work described in the third paper I have designed the educational pathways and trained the teachers. The analysis of the findings was done in collaboration with F.X. Bogner.

Finally, for the preparation of the work that is presented in the fourth paper I had again the responsibility for the educational design. The data collection process as the development of the evaluation instruments was supported by H.Salmi (Heureka Science Centre). In total, I have contributed about a third to this publication.

Concerning the preparation and the four papers the work was allocated as follows: In all three first papers, my own contribution consisted of writing all first drafts and taking the lead in the modification process during completion. In the last paper, my own contribution was equivalent to the other two authors.

Paper 1: “**QUANTITATIVE ANALYSIS OF THE USAGE OF THE COSMOS SCIENCE EDUCATION PORTAL**”

Sofoklis Sotiriou, Franz X. Bogner and George Neofotistos

Journal of Science Education and Technology (submitted)

Paper 2: “**TEACHING REAL-LIFE SCIENCE IN THE LAB OF TOMORROW”**

Sofoklis Sotiriou and Franz X. Bogner

Advanced Science Letter (submitted)

Paper 3: “**VISUALIZING THE INVISIBLE: AUGMENTED REALITY AS AN INNOVATIVE SCIENCE EDUCATION SCHEME”**

Sofoklis Sotiriou and Franz X. Bogner

Advanced Science Letter, 1(1), 114-122 (2008)

Paper 4: “**VISUALIZING THE INVISIBLE IN SCIENCE CENTRES AND MUSEUMS: AUGMENTED REALITY TECHNOLOGY APPLICATION AND SCIENCE TEACHING”**

Hannu Salmi, Sofoklis Sotiriou and Franz X. Bogner

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QUANTITATIVE ANALYSIS OF THE USAGE OF THE COSMOS SCIENCE EDUCATION PORTAL

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ABSTRACT

A quantitative method of mapping the web usage of an educational portal is presented and applied to analyze the behavior of the users of the COSMOS Science Education Portal. As a new science education portal, COSMOS Portal encounters the well-known "new product/service challenge": the major risk in creating a new product/service is getting the service to the users, summarized in the question "if we build it, will they come?" To provide answers to this challenge, the COSMOS Portal operators implemented a validation process by analyzing the web usage data of the portal as registered by the Google Analytics service in the time-period spanning January-October 2009. The web statistics data comprised the total number of all portal visitors (new as well as returning unique visitors) and visitor loyalty parameters (page-views; pages/visit; average time on site; depth of visit; length of visit). The temporal evolution of the number of contributors and the content uploaded to the COSMOS Portal was also analyzed. The quantitative results indicate that the exponential growth of the contributors to the COSMOS Portal is followed by an exponential growth for the uploaded content. New COSMOS users follow the "law of surfing" behavior, a common pattern of surfing behavior in portals. However, new users return to the COSMOS Portal again and again: returning users comprise more than 50% of all COSMOS visits, stay longer on site and visit more pages. Returning visitors are benchmarked against the "law of surfing" and outperform it substantially. These quantitative results benchmark the web usage of the portal and provide its operators with maps of value-added patterns of the portal's offer to the users in the science education community.

Keywords: Science Education Repository, Digital Content, Mapping Users' Behavior, Teachers Professional Development

1. Introduction

The World Wide Web (WWW, Web) has become the standard information system for the world's science education community. From e-learning to information and edutainment, the Web allows inexpensive and fast access to novel and useful services provided by individuals and institutions from all over the world. At the same time, the current availability of digital records has made it much easier for researchers to quantitatively investigate various aspects of human behavior and human activity of accessing information in the World Wide Web (Clauset et al. 2007; Chessa et al. 2004; Dezso et al 2006; Eckmann et al 2004; Johansen and Sornette 2000; Johansen 2004; Stouffer et al 2006; Vazquez et al 2006; Willinger et al. 2002; Barabasi 2005) or other communication media (Candia et al. 2007).

In spite of the advantages of this ubiquitous medium, there are a number of ways in which the Web still does not adequately serve the needs of user communities. Surveys of Web users in the educational communities reveal, as the two most frequently reported problems, slow access and the inability to find relevant information; these problems will be discussed in more detail in Section 2. As a science education portal, the COSMOS Portal (Sotiriou 2008) attempts to solve these problems by designing an effective and efficient classification scheme, organizing the available content according to curriculum needs, offering structured learning materials for classroom use based on the most popular teaching strategies, and at the same time seeking regularities in user patterns that can be taken as a basis for the development of strategies for increasing the suitability of relevant data for the users.

The COSMOS Portal contains educational material in the form of educational content (photos, videos, animations, exercises, graphs, web-links) and of learning activities (structured lesson plans organized according to specific pedagogical models). The main target groups of the COSMOS Portal are science teachers who are looking for high quality materials to enrich the learning opportunities of their students.

As a new portal, COSMOS encounters the “new product/service challenge”. In the past, the major risk in creating a new product/service was the feasibility of the technology. Nowadays, the product/service development cycle is more predictable, thanks to the greater availability of subcomponents and robust development tools. So the biggest risk for most new products/services has shifted from getting the product/service to work, to getting it to the users.

To provide an answer to this challenge, the COSMOS Portal operators implemented a validation process by analyzing the web usage data of the portal as registered by the Google Analytics service in the time-period spanning January-October 2009. The web statistics data comprised the total number of all portal visitors (new as well as returning unique visitors) and visitor loyalty parameters (page-views; pages/visit; average time on site; depth of visit; length of visit). The temporal evolution of the number of contributors and the content uploaded to the COSMOS Portal was analyzed.

This paper is structured as follows: Section 2 presents the issues and the challenges underlying the re-use of digital educational resources in the classroom. Section 3 presents the educational design and the content of the COSMOS Portal and Learning Repository. Section 4 measures quantitatively the web usage of the COSMOS Portal focusing mainly on its content and contributor base growth. Section 5 presents the COSMOS users’ web usage statistics and reveals distinct daily usage patterns between the initial phase of the portal’s operation and a later phase. Section 6 introduces a method of benchmarking COSMOS usage by “new” and “returning” users, applies the method and compares users’ behavior to the “law of surfing”, and finally discusses the implications of these findings. Based on these quantitative results, Section 7 concludes the paper by discussing the overall implications and answers the research questions.

2. Introducing a culture of sharing and re-use of educational resources

2.1 Digital learning resources

Digital learning resources were initially conceived as a tool to make distance education more efficient by facilitating the teachers' re-use of self-contained modules of educational material (learning objects) for course instruction. They were subsequently recognized to have the potential to be helpful for education in general, providing teachers with innovative proposals to improve their educational practice (e.g. educational materials to carry out problem-based activities), as well as simple information technology tools (e.g. Java applets for simulating complex scientific phenomena) whose implementation or development might have been beyond the individual teacher's reach. However, the diffusion of digital learning resources has not grown sufficiently fast due to a number of factors, such as the fact that computers, despite having been available to the schools since the 80's, are not yet deeply integrated into school activity and curriculum. Moreover, research has highlighted a number of difficulties that still hinder teachers' appreciation and actual use of digital learning resources in the classroom, such as the scarcity of information on the resources' quality and the limited congruence of the metadata standards with the current implications of learning theories. There is also a problem of context: an educational resource suitable for teaching in UK schools may be unsuitable for supporting the teaching of the national curriculum in a school in Greece. Recent approaches to e-learning have largely focused on the re-use of resources in order to develop economies-of-scale and social dynamics effects and thus partially address the low usage of information technology (IT) in the classroom. One problem in focusing on educational resource re-use is that teachers tend to plan their IT-based activities around "instructivist" learning models, which focus on single learners accessing content. However, this does not help bridge the gap between modern pedagogical theory and IT implementation. Recent developments in educational technology allow us not only to go beyond resource re-use but also support implementation of recent pedagogy, in particular social-constructivist learning processes. Interoperable, networked technologies have the potential to support students' collaborative activities, allowing them to source, create, adapt, integrate and store resources in a variety of formats. These new possibilities and the availability of e-learning tools make it easier to use technology to support social-constructivist methods of learning, such as collaborative learning through learning communities (Koper 2004). These learning methods focus on the process of learning and on the learning activities students carry out in order to acquire knowledge of concepts.

2.2 Constraints on the development of re-usable teaching resources

There are factors constraining the development of re-usable learning activities and sharable teaching resources, the most significant of which are the following:

a) Teachers frequently do not possess the skills to develop activities based on a range of educational models. This results in a gap between the application of pedagogy and the effective use of tools and resources. Often, teachers and learners view technology in terms of how it will help them manage resources rather than supporting learning (Timmis et al. 2004).
b) The inability to engage with educational taxonomies (e.g. because of unfamiliarity with the relevant metadata and vocabularies) make it difficult for teachers to search for learning activities from various subject disciplines. Teachers would have to browse through resources and activities, accessing and viewing each one of them in order to understand their potential for supporting effective learning. While browsing could be an effective strategy for a single collection of a small number of activities, it would be difficult to apply for wider searching.
c) e-Learning practice is moving towards the re-use of generative resources (e.g. resources developed during learning tasks). This means that the outputs of learning activities should

also be considered for re-use. However, teachers may not possess the required e-literacy skills (for example, to archive activities) to allow for effective re-use of learning resources and activities.

d) The development of 'definitive resources' can lead to the production of materials that do not cater for individual learning contexts. There is a need for tools that allow the teacher to customize generic components in order to provide a tailored learning experience (Thomas and Milligan 2004). However, there are currently few tools available to allow teachers to support learning activity sharing and sequencing (Britain 2004).

e) Efforts for collecting teaching & learning resources in learning repositories have long been performed (Ochoa and Duval 2009) but school teachers have yet to take advantage of their full potential. Recently, a European initiative aiming at the creation of a common European virtual space for resource sharing and re-using has been deployed (and adopted by Ministries of Education around Europe), namely the Learning Resource Exchange (LRE, http://lre.eun.org) of EUN (European School Network). The potential of interconnecting various school repositories in order to facilitate the formulation of teacher communities around Europe, and the uploading, sharing and re-using of teaching & learning resources, needs to be exploited.

Overall, schools and classrooms, both real and virtual, must have teachers who are equipped with technology resources and skills, and who can effectively teach their subject matter while incorporating technology concepts and skills. Interactive computer simulations, digital and open educational resources, and sophisticated data-gathering and analysis tools are only a few of the resources that enable teachers to provide previously unimaginable opportunities for their students' conceptual understanding.

3. The COSMOS Portal and Learning Repository

3.1 Educational Design

The COSMOS Portal (http://www.cosmosportal.eu) aims at improving science instruction by expanding the resources for teaching and learning in schools and universities and by providing more challenging and effective learning experiences for students. COSMOS comprises a web-based repository of educational content using multilingual vocabularies, which aim to facilitate the end-users' search, retrieval, access and use of both scientific and educational resources. It implements a methodology for designing, expressing and representing educational practices in a commonly understandable way for all science teachers. The COSMOS Portal builds upon state-of-the-art developments regarding the interoperability architectures and metadata standards and the latest advances in learning technologies.

During the first year of operation of the COSMOS Portal, a community of more than 1500 systematic users has been established. This community supports the content enrichment approach by uploading regularly additional materials for classroom practice. The educational materials are certified by the COSMOS Label. The COSMOS Portal uses an IEEE LOM Science Education Application Profile that is used for tagging science education resources. To this end, the guidelines for building application profiles in e-Learning, provided by CEN/ISSS-LTW, have been applied. More specifically, based on the characteristics of the science curriculum, COSMOS has identified controlled vocabularies that indicate possible extensions to the IEEE LOM Standard concerning science curriculum properties (Sampson 2008). Using the COSMOS system, students and teachers become capable of directly applying the theories learned and taught in the classroom to real, hands-on research. They directly experience the procedures involved in a research project and thereby gain a far better understanding of science and engineering. The COSMOS initiative contributes toward changing the present situation in science teaching and learning by implementing the following: (i) teaching science through the use of a network of advanced scientific instruments; (ii) reinforcing interdisciplinary approaches; (iii) promoting inquiry-based learning.

[Fig. 1]

Fig. 1 The COSMOS Portal interface allows for easy search and access to science education materials. The information about the resources (title, description, keywords, IPRs, author, educational level, expected duration in the classroom) is indicated with red color on the figure.

Detailed guidelines have been developed by setting out the conditions and protocols for the submission of content to be posted to the COSMOS Portal, comprising: (i) templates for the development of learning activities (based on a variety of pedagogical models, such as the Inquiry-Based, Guided-Research, Learning-Cycle models); (ii) guidelines for the development of science education content; (iii) guidelines for the development of science education learning activities.

3.2 COSMOS Educational Content

The COSMOS educational repository currently (end of 2009) includes more than 80,000 science education learning objects and activities connected to the science curriculum. It provides easy access to data and tools (e.g. databases of numerous observatories across the world, simulations of physical phenomena), teacher resources (e.g. learning scenarios and lesson plans, professional development materials, exams), student-centered materials (e.g. data library, communication area, student worksheets), applications for observations and collaborative activities. Additionally, the COSMOS repository includes high quality applets simulating important astrophysical phenomena such as eclipsing binaries, stellar evolution on the H-R diagram, lunar phases, planetary orbits, planetary motion, and planetary obliquity. Instructions, simulations, and explorations are offered for both the student and instructor, including assessment. A series of movies (solar and lunar eclipses, meteoroids collapses on lunar surface) are also part of the collection. Table 1 presents the profile of the science education content currently stored in the COSMOS Repository.

Table 1: COSMOS Educational Content and Learning Activities (as of 30/09/2009).

Content Type	Current Population	
Science Education Content	Educational Scenarios, Lesson Plans, Presentations	566
	Images/Graphs	79,847
	Movies and Simulations	205
COSMOS Learning Activities		322
COSMOS Learning Activities (for Mobile Devices)		46 (in English and German)

The educational materials of the portal offer a “feel and interact” user experience, allowing for learning “anytime, anywhere” by employing advanced and highly interactive visualization technologies and also personalized ubiquitous learning paradigms in order to enhance the effectiveness and quality of the teaching and learning process.

[Fig. 2]

Fig. 2 The COSMOS Repository is populated with more than 80,000 images of astronomical objects, such as those presented.

[Fig. 3]

Fig. 3 Two of the educational movies populating the COSMOS Repository: the first is filmed from the Earth, during the Total Solar Eclipse in Siberia on the 1st of August 2008, the second is filmed from a weather satellite (EUMETSAT) and presents the impact of the asteroid 2008 TC3 over Sudan on the 7th of October 2008.

[Fig. 4]

Fig. 4 The COSMOS Learning Activities Authoring Tool facilitates the organization of the Educational Content according to specific teaching approaches that are used in science education. The screenshot above demonstrates the organization of a lesson plan for the Parallax Method according to the Learning Cycle approach. Images, graphs, presentations, explanations are organized and presented as a structured Learning Activity.

The COSMOS Learning Activities span a wide range in order to cover the various users' needs. For example, an individual teacher's content needs and objectives can vary considerably from day to day. A teacher may search for content for classroom use, for lesson planning, for home study or for supporting a visit to a science museum. Each of these scenarios requires customized content with distinct characteristics. The selected materials are linked to the school curriculum, include guidelines and sample worksheets for the students, as well as references and additional information.

Example of a COSMOS Learning Activity: Measuring the Asteroids Rotation Periods
Asteroids present an excellent case for short time observations. Some of them are rotating very quickly (one full turn in less than 24h) giving unique opportunities for observations. The specific activity is introduced in the science curriculum in the framework of the study of periodic motions (at high school or university level). The students select the suitable for the season asteroid and the request from the telescope of the COSMOS network of robotic telescopes to conduct the continuous observations for a certain period. After the completion of the observations, series of images of the asteroid will be available on the COSMOS repository for further use. By processing the images, the students find out that the brightness of the asteroid is changing periodically (see Figure 5). By measuring the light that it is reflected on the asteroids' surface as it turns the students are creating a graph indicating the minimum and maximum values of brightness. From these graphs the student may compute the rotation period of the asteroid

[Fig. 5]

Fig. 5 The Sun's light is reflected on the asteroid's surface as it turns and captured by the CCD camera of the robotic telescope which is following the asteroid for a specific period of time requested by the user. In the images above a full rotation of the asteroid has been captured in ten frames. By measuring the light that it is reflected on the asteroid's surface as it turns the students are creating a graph indicating the minimum and maximum values of brightness (picture in the right). The numbers on the graph represent the 10 frames shown in picture on the left. From these graphs the student may compute the rotation period of the asteroid.

4. Measuring the usage of the COSMOS Portal

<u>4.1 Content and Contributor Base Growth</u>

During the time period under study (January-October 2009), the number of the content (learning objects) uploaded and the number of contributors were analyzed. For this initial 10-month period of operation, 80,000 learning objects were uploaded to the COSMOS Portal from 1500 contributors.

[Fig. 6]

Fig. 6 Size and Contributor Base Growth for the COSMOS Portal, in a log-linear graph, which depicts more clearly the $Y=a+be^{ct}$ functional relationship underlying the temporal evolution of the uploaded content size and the contributor base growth.

The graph in Figure 6 presents the growth of the content uploaded and the number of contributors for the period under study. Ochoa and Duval (2009), who have analyzed numerous educational repositories, have found that repositories mostly grow linearly (even the popular and currently active repositories grow linearly). According to these authors, the main reason for this effect is contributor "desertion". Even if the repository is able to attract contributors exponentially, it is not able to retain them long enough to substantiate high growth rates. Another interesting finding (Ochoa & Duval 2009) is that the typical educational repository has a base of 500 to 1500 active contributors contributing on average 10 learning objects each. Our analysis of the COSMOS data demonstrates a higher level of effectiveness: the exponential growth of the contributors is followed from an exponential growth for the uploaded content. COSMOS users contribute numerous educational materials (about 50 learning objects per contributor) while they visiting the COSMOS Portal again and again. In order to study further COSMOS usage patterns, we have quantitatively analyzed a series of additional parameters, comprising the total number of the COSMOS Portal visits (of all, new, and returning unique visitors); page-views; pages/visit; and a series of parameters that demonstrate visitors' loyalty, such as the average time on site per visit; and the depth of each visit (number of pages visited). The results of the quantitative analysis are presented in the following chapters.

4.2 Mapping the behavior of the COSMOS Portal users

In this paper, we study the behavior of "new" visitors to the COSMOS Portal in comparison with "returning" visitors. This type of information is very important because it will not only help to identify the COSMOS portal's user patterns, but also to benchmark the effectiveness of the portal with respect to theoretical expectations. In particular, we have compared the surfing depth (depth of visit) of the COSMOS users with the surfing depth of the "law of surfing" (Huberman et al. 1998), which has been revealed as an average pattern of surfing behavior. The "law of surfing" is theoretically based on a model that assumes that users make a sequence of decisions before proceeding to another page, continuing as long as the value of the current page exceeds some threshold, and it yields the probability distribution for the number of pages, or depth, that a user visits within a website. The findings of this model have been confirmed by empirical studies (Huberman et al. 1998).

5. Data Analysis

The web usage pattern of the COSMOS Portal, for the time period spanning January – October 2009, was studied. For each day in this time period, the Google Analytics free service records an anonymous but unique user identifier, the length of the visit (time of the stay), the depth of the visit (number of pages visited), and the requested pages. A user who starts surfing at a particular page of the COSMOS Portal is recorded as stopping surfing COSMOS after L links (page-views, clicks) as soon as he/she requests a page from a different web site. If the user later returns to COSMOS, a new length count L is started. Users have no constraints on the COSMOS web pages they visit within the COSMOS portal.

An overview of the aggregate COSMOS web statistics data for "all visitors" and "returning visitors" for the time-period under study is presented on Table 2:

Table 2: Overview of the aggregate COSMOS web usage data

COSMOS Portal Statistics (January 1, 2009 – October 31, 2009); All Users	
Registered Users	1,580 (in October 31, 2009)
Page Views	81,548 (total)

Time on Site	8.2 minutes (for returning visitors: 11.2 minutes)
Pages per Visit	7.9 (for returning visitors: 10 pages/visit)
Available Digital Content	85,000 Learning Objects (in October 31, 2009)
COSMOS Portal Statistics (January 2009 – June 2009) – corresponding to School Year 2008-2009	
Registered Users	1,356 (in June 30, 2009)
Page Views	43,155 (total, for the specific period)
Time on Site	8.4 minutes (for returning visitors: 11 minutes)
Pages per Visit	8.5 (Returning Visitors 10.4 pages/visit)
Available Digital Content	55,000 Learning Objects (in June 30, 2009)
COSMOS Portal Statistics (September 2009 – October 2009) – corresponding to School Year 2009 – 2010	
Registered Users	1,580 (in October 31, 2009)
Page Views	20,916 (total, for the specific period)
Time on Site	7.6 minutes (for returning visitors: 13.5 minutes)
Pages per Visit	7.4 (for returning visitors 11.2 pages/visit)
Available Digital Content	85,000 Learning Objects (in October 31, 2009)

Aggregate web usage results of the COSMOS Portal reveal that the portal's users stay longer, show more loyalty (number of visits), and make more page visits (surfing depth) compared to the "law of surfing" surfing depth (analyzed in more detail and presented in the next section). Although this characteristic reveals increased "stickiness" it might also suggest that COSMOS users need more clicks to find the information they require, that is the portal's users have a hard time finding the information. However, this is not the case regarding the COSMOS portal. A more detailed analysis, based on segmenting the COSMOS users into "new" and "returning" users, reveals that the new users exhibit the "law of surfing" behavior, a typical pattern for casually surfing a portal. However the data indicates that new users return to the COSMOS portal again and again, with returning users comprising more than 50% of all COSMOS visits. Returning users show high levels of loyalty, longer times of stay, and much deeper surfing patterns. In particular, we compare the depth of visits (surfing depth) of the COSMOS returning users with that of the "law of surfing"; their surfing depth outperforms the "law of surfing" depth significantly. As the data on Table 2 demonstrates, returning visitors spend more time, and performing more page views as time passes (11 minutes average time and 10.4 pages/visit on average in the period January – June 2009 to 13.5 minutes average time and 11.2 pages/visit on average in the period September 2009 – October 2009. Furthermore, the web usage statistics demonstrate significant changes in the behavior of the users during the period under study, with returning visitors using more and more often the COSMOS Portal for lesson planning and preparation (in the afternoon hours).

The quantitative results described indicate that the COSMOS portal exhibits patterns of offering substantial and systematic value to its users in the science education community. Direct "traffic" during the whole period from January 2009 to the end of October 2009 comprises 7,441 visits (71.94% of total, whereas visits via search engines are 1,556 comprising 15.04% of total, and visits from referring sites are 1346, 13.01% of total). The surfing depth of the users was registered for all visits for the duration of the study. The data for all users has a mean number of clicks of 7.9 (pages/visit) and an average stay on site of 8.2 minutes. The COSMOS web usage data also provide detailed profiles of depth of visit (up to 19 page-views [clicks]), length of visit, and visitor loyalty, for the three categories of visitors (users), namely, all, new and return visitors. The total number of visitors and page views varies over the week. On Saturdays and Sundays there are about 57% fewer visitors per day (8.25) than during working days (19.2). Similar results can be found for page views. On Saturdays and Sundays there are on average 81.3 page views per day, while during working days there are 199.4 page views, i.e. a reduction of page views at the weekends of nearly 60% as compared to working days. A closer look into the time of day when most of the activities on the portal take place (see Figure 7) supports the assumption that teachers are using the COSMOS Portal for preparation of their lessons, as was anticipated in the initial design considerations of the COSMOS Portal. Figure 6 shows, comparatively, the temporal characteristics of page views as accessed daily in January 2009 and in September 2009. In January, the peak time for COSMOS Portal use is during school hours (10:00-13:00). This suggests that teachers are mainly using the COSMOS Portal during their morning lessons. The distribution of September data varies significantly. As teachers get used to the functionalities of the COSMOS Portal and become more familiarized with the educational activities authoring tools, they start to use it also during their lesson preparation time in the afternoon. As shown in the graph (Figure 7), in September 2009 the number of page views in the afternoon hours (15:00-19:00) increased significantly, peaking at more than 800 page views at 17:00, while a significant number of page views occur during school hours, with a peak of about 600 page views at 12:00.

[Fig. 7]

Fig. 7 Comparison of daily COSMOS use between the launching phase (January 2009) and a later phase (September 2009) of the COSMOS Portal. A significant behavioral change was observed with users in the later phase using the COSMOS Portal mainly in the afternoon hours (peak at 5pm). This effect indicates that users are becoming more familiarized with the tools and the available materials that are designed to support lesson planning and lesson preparation activities.

[Fig. 8]

Fig. 8 Length of visits (time on site) for returning visitors of the COSMOS Portal.

Figure 8 presents the length of visits (time on site) for the returning visitors of the COSMOS Portal. The percentage of staying 3 minutes is less than 50%, with the percentage of staying more than 10 minutes being 33%.

6. Benchmarking the COSMOS portal

In this section, we compare (by regression analysis) the surfing depth (depth of visit) of the COSMOS users with the surfing depth of the "law of surfing". The "law of surfing" is theoretically based on a model that assumes that users make a sequence of decisions to proceed to another page, continuing as long as the value of the current page exceeds some threshold, and yields the probability distribution for the number of pages, or depth, that a user visits within a web site. This model has been confirmed with actual data (Huberman et al. 1998).

The law of surfing determines the probability distribution $P(L)$ of the number of pages L a user visits within a web site, by considering a process, in which there is value (V_{L-1}) in each web-page a user visits, and that clicking on the next page the user assumes that it will be valuable as well. Since the value of the next web-page (V_L) is not certain, the process assumes that it is stochastically related to the previous one. In other words, the value of the web-page V_L is the value of the previous one V_{L-1} plus a random term. Thus, the web-page values can be written as

$$V_L = V_{L-1} + \varepsilon_L \quad (1)$$

where the values ε_L are independent and identically distributed Gaussian random variables. A particular sequence of page valuations is considered as a realization of a random process and so is different for each user. Within this formulation, an individual will continue to surf until the expected cost of continuing is perceived to be larger than the discounted expected value of the information to be found in the future. This can be thought of as a real option in financial economics (Dixit and Pindyck 1994). Note that even if the value of the current page is negative, it may be worthwhile to proceed, since a collection of high value pages may still be found. If the value is sufficiently negative, however, then it is no longer worth the risk of continuing. That is, when V_L falls below some threshold value, it is optimal to stop.

The number of links a user follows before the page value first reaches the stopping threshold is a random variable *L*. For the random walk of Eq. 1 the probability distribution of first-passage times to a threshold is given asymptotically by the two parameter inverse Gaussian distribution (Seshardri 1993)

$$P(L) = \sqrt{\frac{\lambda}{2\pi L^3}} \exp\left(\frac{-\lambda(L-\mu)^2}{2\mu^2 L}\right) \quad (2)$$

with mean $E(L) = \mu$ and variance $Var(L) = \mu^3/\lambda$.

By taking logarithms on both sides, Equation 2 becomes:

$$\log P(L) = -\frac{3}{2}\log L - \frac{\lambda(L-\mu)^2}{2\mu^2 L} + \log\left(\sqrt{\frac{\lambda}{2\pi}}\right) \quad (3)$$

That is, on a log-log plot one observes a straight line whose slope approximates 3/2 for small values of *L* and large values of the variance. As *L* gets larger, the second term provides a downward correction. Thus Equation 3 implies that, up to a constant given by the third term, the probability of finding a group surfing at a given level scales inversely in proportion to its depth,

$$P(L) \propto L^{-3/2},\ or,\ \log P(L) = constant - 3/2 \log L \quad (4)$$

This Pareto-type scaling relation (Huberman et al. 1998; Perline 2005) was verified by plotting the available data on a logarithmic scale. Figure 9 shows that for the range of COSMOS users' visit lengths (according to the Google Analytics detailed registration of 1 up to 20 clicks) the inverse proportionality of Eq. 4 holds well.

[Fig. 9]

Fig. 9 Comparing the law of surfing to the aggregate demand curve of the number of COSMOS returning users as a function of the number of pages visited (clicks), based on the data collected from the COSMOS Portal for the time period spanning January – October 2009. The fitted inverse Gaussian distribution has a mean of $\mu = 4$ and $\lambda = 3.6$.

In order to benchmark the web usage of the COSMOS portal against the validity of Equation 2, we performed a log-log regression analysis of the data collected in the time period January 1, 2009 through October 31, 2009, by means of the model (which corresponds to the terms in Equation 3), namely:

$$\log P(L) = C_1 + C_2 \log L + C_3 L + C_4 (l / L) \quad (5)$$

The detailed regression results will be presented in a companion paper. Because of the low t-statistic values of coefficients C_3 and C_4 , the third and fourth term in the right hand side of Equation (5) are not statistically significant and should be omitted. This can be explained because of the small values of L (up to 20) and the large values of the variance.

Therefore we perform regression analysis (OLS) using the model

$$\log P(L) = C_1 + C_2 \log L \quad (6)$$

which corresponds to the terms of Equation (4). The coefficient C_2 corresponds to the exponent the numerical value of which is –3/2 for the law of surfing (inverse Gaussian).

As can be seen in Table 3, comparison of the COSMOS web usage exponents (that is, the values of the coefficient C_2 of the Equation 6 against the exponent of the inverse Gaussian distribution) indicates that:

a) new COSMOS users conform closely to a typical “law-of-surfing” behavior (the value of the coefficient C_2 is very close to the value of –3/2). We argue that the value of the coefficient C_2 could in reality be closer to the value of –3/2; however the COSMOS Portal does not monitor the user’s origin by sending a special-purpose cookie, but, instead, relies on the Google Analytics data, which may identify some returning users as new users due to a randomized IP address assignment.
b) returning COSMOS users’ surfing depth outperforms the “law of surfing” - the COSMOS Portal’s returning users exhibit a deeper surfing behavior.

Table 3: Comparison of COSMOS regression results (Equation 6) against the inverse Gaussian (“law of surfing”) exponent.

COSMOS users	**Value of C_2**	**Standard error**
All visitors	-1.160	0.052
New	-1.369	0.075
Return	-0.997	0.065
Law of surfing (inverse Gaussian distribution)	-1.500 (= -3/2)	

The COSMOS portal is thus benchmarked against the law of surfing. As the results demonstrate, new users follow a typical surfing pattern, while, however, returning users outperform this pattern, “foraging” frequently (Edwards et al. 2007), deeper and longer for the science education content offered by the COSMOS Portal.

7. Conclusions

The COSMOS Portal has been designed to facilitate science teachers’ search, retrieval, access and use of both scientific and educational resources. It introduces teachers to an innovative methodology for designing, expressing and representing educational practices in a commonly understandable way through the use of user-friendly authoring tools. The COSMOS Portal in its first year of operation collected more than 80,000 educational objects, and was supported by a very active community of 1500 science teachers from many European countries. The content of the COSMOS Portal is available in English, German, Greek, Finnish, Swedish and Turkish. The aim of the work described in this paper is to design and deploy a systematic approach for measuring the web usage effectiveness of an educational portal, such as the

COSMOS Portal. Data from the COSMOS Portal use were collected via the Google Analytics monitoring system.

According to our findings, the exponential growth of the contributors to the COSMOS Portal is followed by an exponential growth of the uploaded content. COSMOS users contribute numerous educational materials (about 50 learning objects per contributor) while they repeatedly visit the COSMOS Portal. In order to study further these results, a series of additional parameters were studied, comparing the initial phase of the operation of the COSMOS Portal with a subsequent phase. These parameters comprise the total number of the COSMOS portal visitors (all, new, and returning unique visitors); page-views; pages/visit; and a series of parameters that demonstrate visitors' loyalty such as the average time on site per visit and the depth of each single visit (number of pages visited). According to the data, a significant behavioral change has been identified as returning users access the COSMOS Portal more and more frequently in after-school hours, presumably during the preparation of lessons, as the educational design of the COSMOS Portal had expected.

Furthermore, we benchmarked the COSMOS web usage against the law of surfing. As the quantitative results demonstrate, new users follow a typical surfing pattern. However, returning users (who comprise more than 50% of all COSMOS visitors) outperform this pattern, "foraging" frequently, deeper and longer for the science education content offered by the COSMOS Portal.

This method can also be used for a number of interesting web applications. Because of the web's digital nature and great use, it is relatively easy to obtain online data that could reveal more novel patterns of information foraging, and one could extend the method to determine the distinct characteristics of different user communities.

As the world becomes increasingly connected by the internet and the web, the discovery of new patterns in web usage can support the design, growth and development of effective science education portals.

8. Acknowledgements

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Figures to paper 1

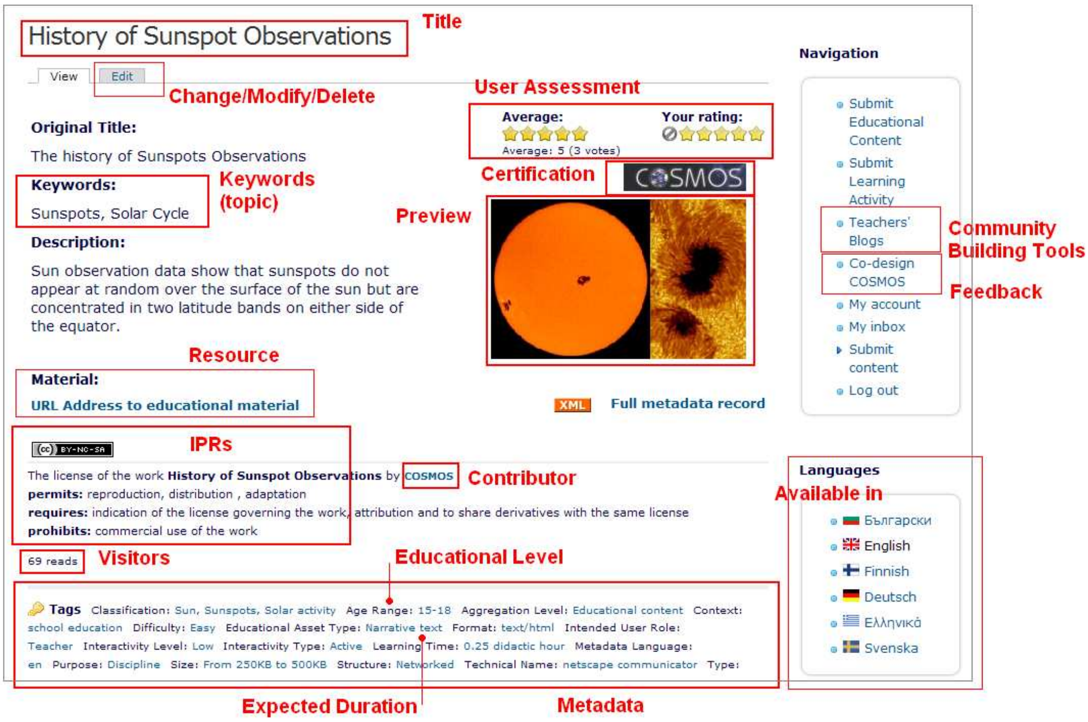
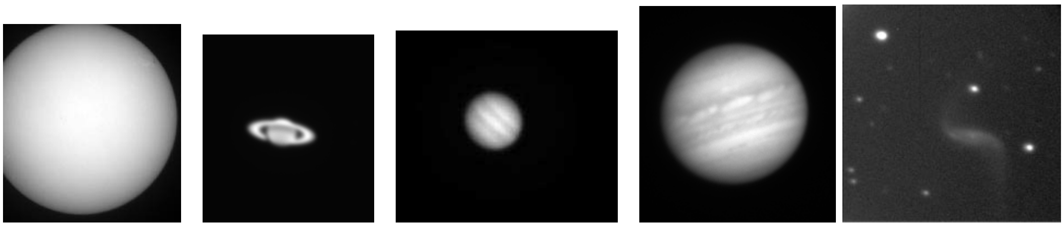


Fig. 1



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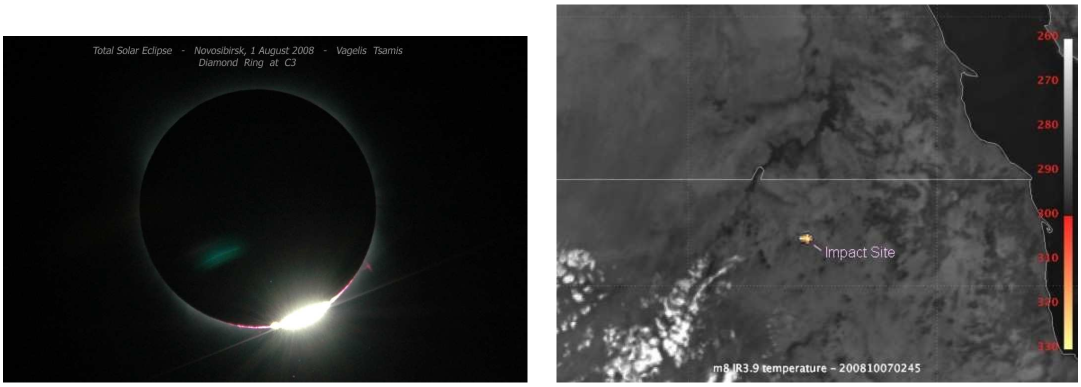
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Diamond Ring at C3
270
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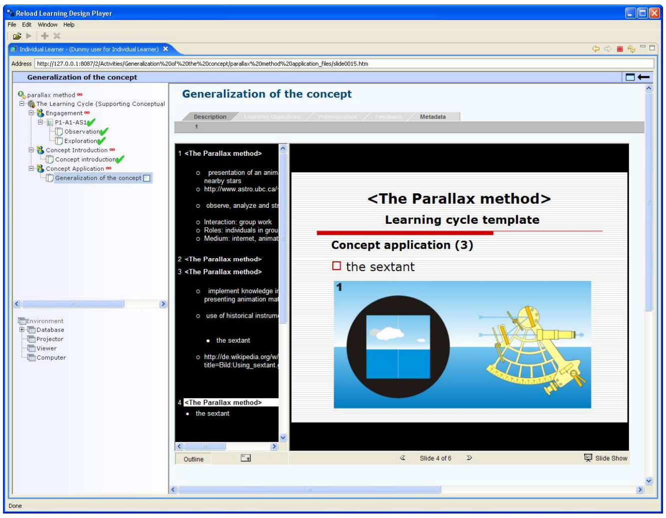
Fig. 3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Generalization of the concept
Generalization of the concept
<The Parallax method>
Learning cycle template
Concept application (3)
the sextant

Fig. 4

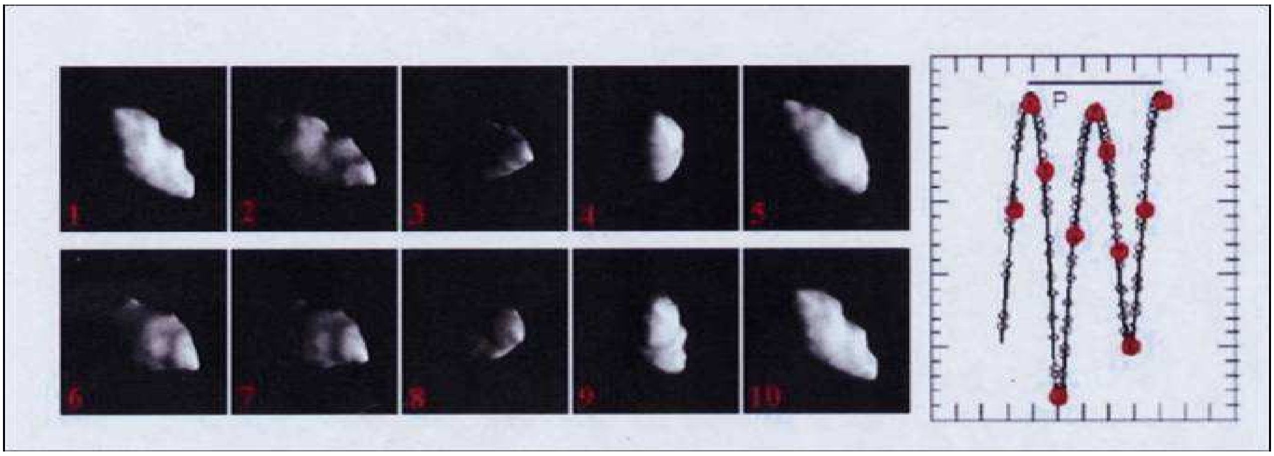
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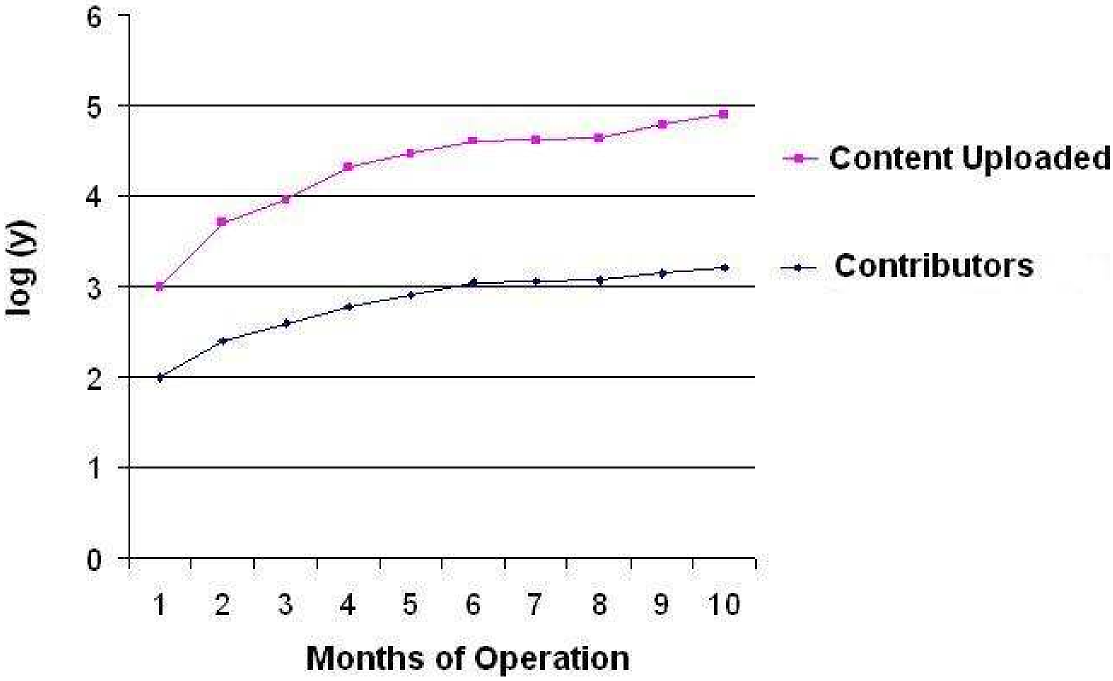
Fig. 5


6
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3
2
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0
log (y)
1
2
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4
5
6
7
8
9
10
Months of Operation
Content Uploaded
Contributors

Fig. 6

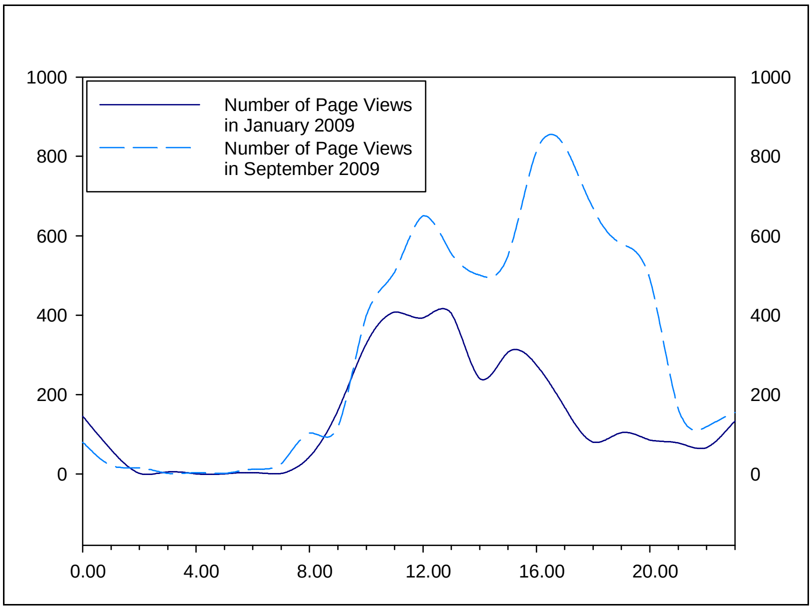
1000
800
600
400
200
0
Number of Page Views in January 2009
Number of Page Views in September 2009
0.00
4.00
8.00
12.00
16.00
20.00

Fig. 7

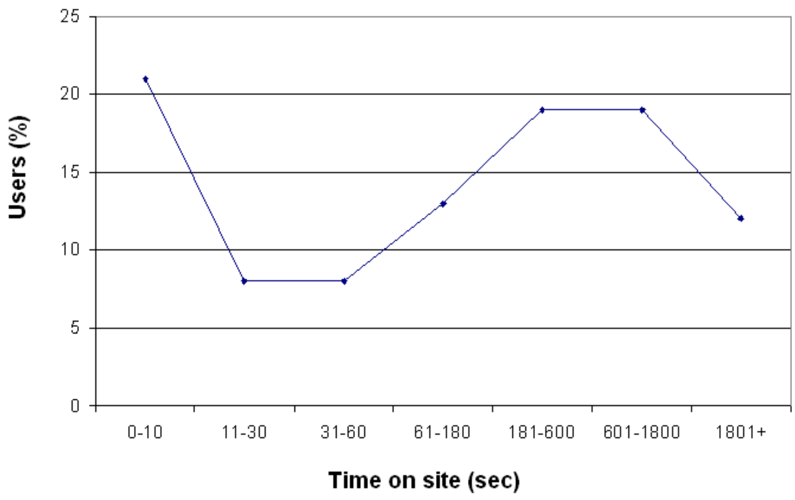
Users (%)
25
20
15
10
5
0
0-10
11-30
31-60
61-180
181-600
601-1800
1801+
Time on site (sec)

Fig. 8

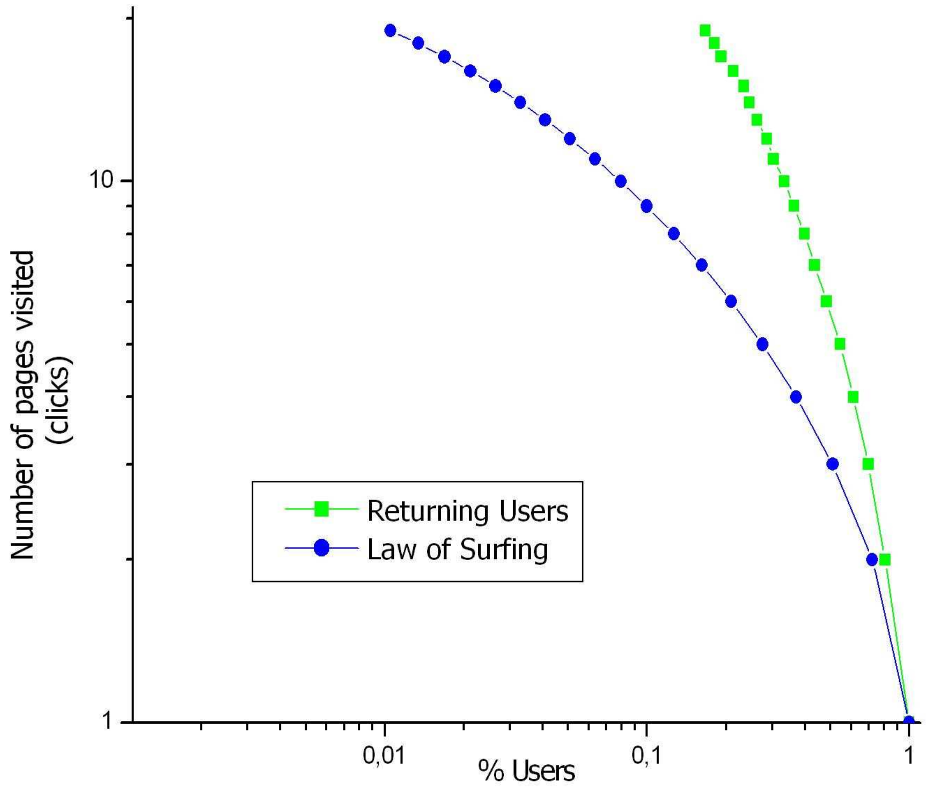
Number of pages visited
(clicks)
10
1
0,01
0,1
1
% Users
Returning Users
Law of Surfing

Fig. 9

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Teaching Real-Life Science in the Lab of Tomorrow

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Abstract

Numerous studies of science teaching have shown that we should revise the way that science is taught in our schools, and promote pedagogical practices based on inquiry-based methods. Inquiry-based science education has proved its efficiency at both primary and secondary levels in increasing students' interest and attainments levels while at the same time stimulating teacher motivation. This paper presents an innovative way to introduce inquiry-based methods into science classrooms using advanced technological applications. The Lab of Tomorrow system consists of a series of tiny, programmable devices that are embedded in clothing, footballs and other items. The system monitors the wearer's running pace, body temperature, heart rate or the acceleration of a ball. This practical information can be translated into examples of science theory, raising interest and motivation among students, and improving the learning process. In this way everyday activities of the students become the subject of experimentation. They personally experience the procedures involved in an authentic research project and thereby gain a far better understanding of science. This paper describes the systematic procedure that was adapted to monitor students' and teachers' activities while using the Lab of Tomorrow system. 400 students from 18 schools from Greece, Germany, Austria and Italy were involved in the study for a period of 8 months (one school year) during their science lessons. Quantitative and qualitative data were collected and analyzed in detail. The analysis of the findings demonstrates that there is significant improvement of learning outcomes for the students in all cases in both physics and mathematics. Additionally the results of the extended lesson video capturing study also demonstrate that the Lab of Tomorrow system offers a great opportunity to teachers to adopt inquiry-based methods in their lessons and to implement teaching strategies that can facilitate learning about scientific inquiry, developing the abilities of inquiry, and understanding scientific concepts and principles.

Key words: ICT, wearable computer, video analysis, science education, inquiry

1. Introduction

Understanding science is essential in today's society. The public's understanding of science is largely influenced by its experiences in science classrooms. It is therefore important that science teachers understand science and give an accurate representation of it in their classrooms (Bybee et al., 2008). Science is defined as a body of knowledge, a process of inquiry, and the people involved in the scientific enterprise. Science teachers usually concentrate on the body of knowledge that forms their discipline. Students should also understand the process of scientific inquiry; that understanding should come through their experiences with the process in the science classroom and outside school. Different models of scientific inquiry have been developed and extensively validated over the last years. The accumulation of valid reliable knowledge was shown to be the aim of all the models (Bybee et al., 2008). Science teachers should understand the strengths and weaknesses, the procedures, and the logical problems of the different models of inquiry. In the science classroom there should be a balance in emphasis on science as a body of knowledge, a process, and a human enterprise.

The publication of the "Science Education Now: A renewed Pedagogy for the Future of Europe" report (Rocard et al., 2007) brought science and mathematics education to the top of the educational goals of the member states (following similar actions in US, NRC 2007). The authors argue that school science teaching needs to become more engaging, based on inquiry and problem solving methods and designed to arouse the interest of young people. According to the report, the origins of the alarming decline in young people's interest in key science studies and mathematics can be found, among other causes, in the old fashioned way science is taught at schools. Although the crucial role of positive contacts with science at early stage in the subsequent formation of attitudes toward science has been identified (PISA, 2006), traditional formal science education too often stifles this interest and, therefore, may negatively interact with the development of adolescents' attitudes towards learning science. Kinchin (2004) pointed out that the tension created between objectivism (the objective teacher-centered pedagogy) and constructivism (the constructive and student-centered pedagogy) represents a crucial classroom issue influencing teaching and learning. The TIMSS (Third International Mathematics and Science Study) 2003 International Science Report (Martin et al., 2004) specifically documented that internationally, the three most predominant activities accounting for 57 percent of class time were teacher lecture (24%), teacher guided student practice (19%), and students working on problems on their own (14%) in science classes in the European countries participating in the study.

Therefore, it appears that the current science classroom learning environment is often a mixture of divergent pedagogies and diverse student orientations or preferences (Chang & Tsai, 2005; Chang, Hsiao, & Barufaldi, 2006). The fact is that there is a major mismatch between opportunity and action in most education systems today. It revolves around what is meant by "science education," a term that is incorrectly defined in current usage. Rather than learning how to think scientifically, students are generally told about science and asked to remember facts (Alberts, 2009). This disturbing situation must be corrected if science education is to have any hope of taking its proper place as an essential part of the education of students everywhere.

In addition to the these issues, the science learning environment (classroom and lab) seems to undergone no significant changes for the past decades. Recent research on learning and instruction has substantially advanced our understanding of the processes of knowledge and skill acquisition (Bybee et al., 2008). However, school practices have not been innovated and improved in ways that reflect this progress in the development of a theory of learning from instruction. School practices in a realistic sense are centered on the school learning environment. It is generally recognized among practitioners that our school science learning environment has neither been innovative nor reformed to reflect this new knowledge with respect to learning and teaching. Moreover, modern technologies beyond the use of computers and internet in the school have not been fully integrated/incorporated in current science learning environment.

According to the recent report “Science Education in Europe: Critical Reflections” (Osborn & Dilon, 2008) the deeper problem in science education is one of fundamental purpose. Schools, the authors argue, have never provided a satisfactory education in sciences for the majority. Now the evidence is that it is failing in its original purpose, to provide a route into science for future scientists. The challenge therefore, is to re-think science education: to consider how it can be made fit for the modern world and how it can meet the needs of all students including those who will go on to work in scientific and technical subjects, and those who will not (Kali & Linn, 2009).

In this framework the Lab of Tomorrow system (www.inlot.eu) (Orfanakis et al., 2005) provides more challenging, authentic and higher-order learning experiences, more opportunities for students to participate in scientific practices embedded in social interaction using the discourse of science and work with scientific representations and tools. It enriches and transforms the students’ concepts and initial ideas. Furthermore the use of the system offers opportunities for teaching tailored to the students’ particular needs while it provides continuous measures of competence, integral to the learning process that can help teachers work more effectively with individual students.

INCLUDEPICTURE "http://www.laboftomorrow.org/images/home2.gif" * MERGEFORMATINET

Figure 1: "Kick – life into the classroom" through the Lab of Tomorrow system: Everyday activities of the students become the subject of experimentation through the use of wearable sensors embedded in their cloths and their equipment.

2. Materials and Methods

2.1. Description of the Lab of Tomorrow system

Wearable computers and intelligent sensors were embedded in everyday objects (e.g. t-shirts, balls) and used during students' usual activities. The sensors, called "axions", were able to record the acceleration of the body (or of the ball), the temperature of the body and the heart rate or the wearer. The recorded data were used by a specially designed user Interface to graph trends and patterns and investigate the laws of physics. Students had the opportunity to collect data from a variety of sensors, compare their measurements and design new experimental activities on their own. In this way, teaching offers as many links as possible between the natural sciences and daily life. In order to obtain the maximum flexibility regarding both the lesson plans that were designed to support the system's introduction in the schools and the students' learning processes, the system was designed using a modular approach: Small devices collected data during students' experimental activities. Students were thus enabled to easily quantify these observations, identify schemes or patterns and derive hypotheses and theories.

Figure 2: The Lab of Tomorrow system demonstrates ways for the re-engineering of the high school science laboratory into an engaging, thought-provoking, and challenging environment, a pathway to the real scientific world. Through the use of embedded sensors, data collected during a series of experiments were transmitted and presented to the students in real time, demonstrating the basic laws of the physical phenomena taking place.

A combination of the axions forms the integrated Lab of Tomorrow system. It consists of the following modules: a wearable system called SensVest, embedded in a t-shirt, the Leg and Arm Accelerometer, the Ball Accelerometer, embedded in a ball, the Base Station for the data collection and organisation and a user interface for data presentation and analysis. The SensVest is a t-shirt designed to carry components that measure and transmit physiological data to the base station. It is equipped with various sensors. A temperature sensor located under the armpit is used to record the body temperature of the user; a pulse sensor – attached to the user's chest– records the heart rate. Additionally, accelerometers embedded in the SensVest allow for the measurement of the acceleration of the body and a leg or an arm. The SensVest offers the opportunity to add additional sensors to expand experimental possibilities. The data from all sensors is collected and processed by a microprocessor unit. An integrated communication unit transfers the processed data to the base station. Both units are located in the back of the t-shirt. The placements of the units and the sensors were selected on the basis of an ergonomic study, so that the confounding variables are reduced to a minimum. The leg accelerometer is a small device attached to the leg. It enables measurement of the acceleration of a foot while for example kicking a ball. A small sensor collects the data which were processed immediately by a microprocessor and transmitted to a receiving unit located at the hip which is connected in turn to the SensVest's microprocessor unit. One of the key axions of the system is the ball accelerometer. An accelerometer measuring three dimensions and a communication unit was embedded inside a ball. To mount the accelerometer in the ball a foam type material was used in order to keep the accelerometer and communication units in the centre of the ball: the ball was filled with this material and the accelerometer – placed in a plastic tube – can be inserted through a hole. By this approach possible impacts of external forces and extreme mechanical stress could be avoided. In addition the device can easily be accessed. The Base Station is responsible for the initialization of the system, collection of all transmitted data and the proper formatting of this data and subsequent dispatch to the system workstation. The Lab of Tomorrow user interface is considered the central component of the system. It is the interconnection between the technical world of the axions and the students' activities within the experimental setting. The user interface uses a database in which all the received data is stored synchronously. The miscellaneous sensors' data can later be analyzed and processed by the students. Apart from storing and organizing the incoming data, the user interface serves another most valuable function. As a pedagogical tool it provides the links between science teaching in classroom environment and the phenomenon. The user interface software has been designed with the pedagogical framework in mind. The user interface enables various students' actions like data accessing, plotting data on a graph, creating a mathematical model to fit the data and combining graphs of different sources. The user interface software is intended to support students in recognizing scientific methods and it can be used to solve problems or to study phenomena in their everyday lives.

2.2. The Lab of Tomorrow Educational Design

Any learning process is challenged by the increasing complexity in science. That is a growing process of finding intrinsic structures of the content area and rules. This provides a theoretically guided model based on a part of reality and features of scientific inquiry. The necessary systemization of long term planned and cumulative learning contributes to a well-arranged, internally and vertically (in time) linked adaptive knowledge which can be applied flexibly and in different situations. Teaching and learning in science is successful, if it is possible to realize a sequence of topics that both guarantee systematic learning (vertical knowledge transfer) and situation orientated learning with everyday tasks and problems (horizontal knowledge transfer). The orientation to methods of scientific research provides the possibility for the students to learn about the subject and cross-subject methods of reasoning and working. In the learning groups there should be opportunities for dialogues, at first guided by the teacher, but becoming more and more autonomous and aimed at the development of scientifically orientated conceptions and concepts. Students should have the possibility to describe their individual learning pathways and their individual solutions of a problem. Creativity, effort and flexibility must be acknowledged. A teaching method contains the teaching sequences, teaching methods and the structural elements of methods of teaching and learning and has to refer to research on teaching and learning. Therefore in the case of the Lab of Tomorrow approach the proposed lessons were organized into tasks according to two levels of understanding as two sequences of tasks to support conceptual growth. In addition, two alternative pathways with different learning aims were offered providing individual experiences for small groups of students.

A “Lab of Tomorrow” curriculum was set up taking into account the national curricula. A series of lesson plans was developed corresponding to this curriculum always containing two main parts: (i) General information concerning the lesson, its curriculum relationship, implementation, instruction for teachers, lesson duration, and required materials. It also specified the educational aims and derived educational and didactical objectives for the respective lesson. Finally, common students’ misconceptions on the teaching subject are discussed to provide the teacher with a better notion of students’ initial conceptions before instruction. (ii) The second part provided substantial information about the educational phases, proposing ideas on how to stimulate the students and describing experimental activities. A variety of possible observations, data analysis and conclusions were listed. To support consolidation of the respective contents a series of exercises and questions and further activities is suggested in form of a students’ worksheet.

2.3. The Lab of Tomorrow: Scenarios of Use

Using the Lab of Tomorrow system teachers and students were be able to conduct their own experiments using everyday objects. In this way they were be able to observe and thus better understand the relevant physical laws. As a result science was brought closer to high school students in a more motivating way. The way students and teachers will experience science through the Lab of Tomorrow is expected to have a lasting positive impact on students’ attitudes towards science and experimentation.

The participating students were able either to perform real life experiments themselves or to select materials for experimentation from the Lab of Tomorrow educational Repository. The data were collected and analyzed by the students using tools fully compatible with existing and commonly used programs [the spelling “program” is used internationally, not just in the US, to designate a computer program]like MS Excel. Students personally experience the procedures involved in an authentic research project and thereby gain a far better understanding of science.

2.4. Research targets

The primary target of our research work was to assess students' performance after they attended the Lab of Tomorrow lessons. Another important aspect in the evaluation of students' learning is the course of the students' learning processes. Since the learning processes, using an advanced technological system like the Lab of Tomorrow, mainly depend on the students' abilities in the usage of the technological equipment, it is important to evaluate the students' attitude and aptitude using modern technology. Therefore the following research targets can be formulated as to the evaluation of the Lab of Tomorrow approach:

- Students' performance before and after attending Lab of Tomorrow lessons
- Students' learning processes
- Students' attitude and aptitude regarding modern technology
- Lesson implementation and teaching approaches

2.5. Methodology and Evaluation Instruments

The evaluation of students' performance required an assessment tool capable of coping with the different national conditions of the participating countries; namely language, school curricula and culture. A reliable questionnaire accomplishing these qualities has been used in the scope of TIMSS (Martin et al., 2004). The TIMSS items are Rasch-scaled which allows the comparison of different topics and countries on a large scale related to students' performance. The TIMSS project collected educational achievement data at the fourth and eighth grades to provide information about trends in performance over time together with extensive background information to address concerns about the quantity, quality, and content of instruction (Martin et al., 2004). To inform educational policy in the participating countries, this world-wide assessment and research project also routinely collected extensive background information about the quantity, quality, and content of instruction. For example, TIMSS 2007 (Martin et al., 2008) collected detailed information about mathematics and science curriculum coverage and implementation, as well as teacher preparation, resource availability, and the use of technology. To allow an attribution of the actual test results to the specific Lab of Tomorrow lessons the evaluation was organized as a pre-, post-evaluation with treatment and control groups. The results of TIMSS (Martin et al., 2004) served as an additional control group with particular focus on students' performance. Table 1 presents the main research targets of our study and the instruments used. Table 2 presents the evaluation sample.

Table 1: Assessment tools concerning the research targets as specified.

Students performance after attending Lab of Tomorrow lessons	TIMSS Questionnaire
Students learning processes	Video Documentation
Students attitude and aptitude regarding modern technological equipment	Video Documentation
Lesson characteristics	Video Documentation
Lesson implementation	Video Documentation

Table 2: Evaluation Sample. Our study was conducted in 18 high schools in Greece, Germany, Austria and Italy. Some 400 students (15-16 years old) participated in this study.

Country	Number of Schools	Type	Number of Students	Age (Years)
Greece	5	Treatment	102	15-16
Germany	4	Treatment	108	15-16

Austria	6	Treatment	98	15-16
Italy	3	Treatment	89	15-16

For the needs of the Lab of Tomorrow evaluation the “TIMSS population II test” was used. It is designed for 15 years old students, its content matches that of the curriculum of the participating countries and the content of the project. In pre- and post-test different booklets were used to avoid recognition effects. Because of the TIMSS international studies’ rotation design pre- and post-tests are comparable. The evaluation of the pedagogical framework was strongly connected with the analysis of the implementation of the lessons. To obtain information about major characteristics of the lesson implementation, we video-captured lessons while the Lab of Tomorrow system was in use in the classroom. Additional information like for example the lessons’ structure, students’ time-on task or the teachers’ educational aims was obtained by analyzing the video documentation.

2.6. Evaluation Plan

The implementation process was realized in two phases. In the first phase teachers had to adopt specific lesson plans (prepared by the research team) appropriate to the use of the system in their classrooms. Then, during the second implementation phase teachers and students had the opportunity to use the system to perform self-initiated and –planned activities and experiments. Just before the first phase the TIMSS pre-tests were administered. Both phases were accompanied by video documentation according to the video guidelines. After the end of the second phase of implementation the TIMSS post-test were administered. The duration of the two phases of implementation was a full school year (8 months). The time interval between the applications of the TIMSS test was about 9 months.

Figure 3: Time line and main phases of the evaluation plan. The graph indicates the timing of the various instruments that were applied during the implementation of the classroom centred activities.

In the framework of the implementation of the proposed activities, the lessons were classified into three different categories, according to the different phases of the classroom implementation: (i) Lesson type A: Introductory lesson, in which the teacher presented and explained the functionalities of the Lab of Tomorrow system. (ii) Lesson type B: Lesson with simple experiments, in which students performed experiments with the Lab of Tomorrow system initiated by the teacher, based on the scenarios developed by the research team. (iii) Lesson type C: Lesson with complex experiments, in which students performed experiments with the Lab of Tomorrow system initiated by them. The first phase of implementation included lessons of type A and B, while the second phase of implementation included lessons of type B and type C.

3. Results and Discussion

3.1 Data Analysis from the TIMSS questionnaires

TIMSS used item response theory (IRT) methods to summarize the achievement of each grade on a scale with a mean of 500 and standard deviation of 100. The TIMSS science scales for the fourth and eighth grades were established based on the 1995 assessments, and the methodology enables comparable trend measures from assessment to assessment within each grade. It should be noted that, while the scales for the fourth and eighth grades are expressed in the same numerical units, they are not directly comparable in terms of comparing the achievement or learning at one grade to that of the other. That is, achievement on the TIMSS scales cannot be described in absolute terms (like all such scales developed using IRT technology). Comparisons can only be made in terms of relative performance (higher or lower), for example, among countries and population groups as well as between assessments.

Table 3 presents the mean average values of the pre-test and post-test along with the differences and standard deviations per country for both science and mathematics results.

Table 3: The mean average values of the TIMSS pre-tests and post-tests.

Science Results						
Country	Type	N	Pre-Test (SD)	N	Post-Test (SD)	Difference
Greece	Treatment	102	585 (44)	102	621 (33)	36
Germany	Treatment	108	576 (42)	108	625 (40)	49
Austria	Treatment	98	592 (35)	98	628 (32)	36
Italy	Treatment	89	580 (46)	89	610 (42)	30
Mathematics Results						
Country	Type	N	Pre-Test (SD)	N	Post-Test (SD)	Difference
Greece	Treatment	102	590 (41)	102	632 (33)	42
Germany	Treatment	108	609 (38)	108	635 (32)	36
Austria	Treatment	98	586 (51)	98	612 (42)	26
Italy	Treatment	89	582 (56)	89	610 (52)	28

The data demonstrate that in all cases a substantial increase occurred in the students' performance in both science and mathematics. Data from the participating schools in Greece and in Germany showed an increased impact of the Lab of Tomorrow intervention on students' achievement in comparison with the data from Austria and Italy. [consider commenting on the markedly higher SDs in the case of Austria and Italy]The fact is that the implementation in Greece and in Germany was realized by teachers quite experienced in the methodology, as they have been working with the systems for a long period. In all cases the teachers also had long experience in using advanced technological applications in their classrooms.

3.2 Video Analysis

The findings from the quantitative study are very well supported by the analysis of the video results. Our study examined classroom teaching practices through in-depth analysis of videotapes of eighth-grade lessons in mathematics and science. The study provides a rich descriptions of mathematics and science teaching as it was actually experienced by eighth-grade students in the participating countries. We are presenting a comparative analysis between the Lab of Tomorrow approach and Inquiry Based models that are proposed in the framework of current reform efforts in many countries in Europe (Rocard, 2007, Osborn, 2008). The videos of the lessons were classified into three different categories, according to the different phases of the classroom implementation (Lesson type A, B and C).

For the purpose of the analysis of the recorded lessons a set of main lesson sub-activities were identified and agreed by the evaluation team, and a video workshop was held to permit the video analysis process to be conducted locally. In the course of the workshop coders from the participating countries were trained systematically in the use of the category system and subsequently coded the videos from their respective countries. As the detailed description of the category system for the description of the lesson sub-activities for the video analysis is presented in Sotiriou et al. (2004), only a rough overview will be provided here: Concerning the analysis of the actual lesson implementation, e.g. teaching methods used, a set of categories regarding the superficial characteristics of lessons (Category Set A) was compiled from the extensive category system developed by Reyer et al. (2004) for the analysis of apparent and deep structure of lessons. To obtain information about the ICT related activities of students, a set of categories regarding computer use and learning physics was developed (Category Set B). For the analysis concerning educational aims and content-related actions two more category sets were created based on the work of Reyer et al. (2004): Categories regarding learning physics and modelling (Category Set C) and categories regarding application and transfer of the acquired knowledge (Category Set D). The video documented lessons were split into coding intervals of 20 seconds. Each interval was coded using the category sets outlined above. The analysis of the video documented lessons according to these category sets are described in the following paragraphs.

Students Time on Task

One of the main issues explored in the framework of the video analysis was the students' involvement in the proposed activities. Science deals with the study of nature and the world around us, so teaching science cannot be separated from daily experiences resulting from student's interaction with the physical phenomena. The connection between tangible physical phenomena and scientific problems provides students with the ability to apply science everywhere, not only in specially designed experiments under the laboratory's controlled conditions.

Figure 4: The profile of the lessons distributed to the different students' tasks for the three different types of lessons. The graph presents a significant decrease in teacher instruction along with a significant increase of the students' involvement as we move from lessons type A to lessons type C.

Teachers' Action

To retrieve information about the actual teaching methods in use, the video data were coded into categories in order to validate the implementation of the proposed approach in real situations. Figure 5 presents the profile of the video'd lessons. As the Lab of Tomorrow system is introduced in the classroom and both students and teachers are getting familiarized with the approach, average "Lecturing" time decreases (from 35% to 10%) while "Discussion/ Dialogue" and "Testing/Inquiry" time increased, as is expected in a learner centred approach.

Figure 5: The profile of the lessons assigned to the different teachers' activities for the three different types of lessons. The graph presents a significant decrease in the teacher's

presentation time, along with a significant increase in the students' involvement as we move from lessons type A to lessons type C.

3.3 Introducing Inquiry Based Science approaches in the classroom using the Lab of Tomorrow system

Inquiry based learning has been officially promoted as a pedagogy for improving science learning in many countries (Rocard et al., 2007). The key features of teaching science by inquiry are the following:

- Learner engages in scientifically oriented questions.
- Learner gives priority to evidence in responding to questions.
- Learner formulates explanations from evidence.
- Learner connects explanations to scientific knowledge.
- Learner communicates and justifies explanations.

Inquiry can be defined as "the intentional process of diagnosing problems, critiquing experiments, and distinguishing alternatives, planning investigations, researching conjectures, searching for information, constructing models, debating with peers, and forming coherent arguments" (Linn, Davis, & Bell, 2004). Our study at this stage was based on the characterization of the video documentation to design the exact profile of the lesson and demonstrate [do you mean "examine", or "examine the effects of"? Unclear]the appearance of the specific features of inquiry in the framework of the Lab of Tomorrow lessons. Figure 6 presents the sequence of appearance of the main features of inquiry in the lessons of type B and C. About 200 lesson hours of video captures were analyzed to produce this graph, that demonstrates that the key features of inquiry are presented with a frequency of about 90% in lessons of type C where the Lab of Tomorrow system is effectively used in the classroom.

Figure 6: The profile of the lessons assigned to the essential features of inquiry for lessons of type B and C. The graph presents that all the essential features are presented frequently in the proposed Lab of Tomorrow lessons (Type C).

4. Conclusions

The Lab of Tomorrow approach brings into the classroom activities that are based on real-world problems and involves students in finding their own problems, testing ideas, receiving feedback, and working collaboratively with other students or practitioners beyond the school classroom; provides tools and scaffolds that enhance learning; supports thinking and problem solving, model activities and guide practice; represents data in different ways, and is part of a coherent and systemic educational approach. A series of lessons were designed and implemented in real school environments. These activities were fully in line with the science curricula of the participating classrooms as well as they were linked with the students' everyday activities. When the teachers and the students were familiarized with the approach, they were asked to design and develop their own experiments using the Lab of Tomorrow system and use different activities as a mean of experimentation. In the present study, our results from different classrooms in different countries been involved in the Lab of Tomorrow activities during a whole school year demonstrate that there is significant improvement in the learning outcomes in both, physics and mathematics. Additionally the outcomes of the extended lesson video capturing also demonstrate that the Lab of Tomorrow system offers a great opportunity to teachers to adopt inquiry based methods in their lessons, methods that have proved their efficacy in increasing students' interest and attainments level while at the same time stimulating teacher motivation. Through the analysis of 200 lesson hours we mapped the science lessons' profile with the use of the Lab of Tomorrow system and demonstrated that a) it supports a reversal of science instruction from mainly deductive to inquiry based approach, b) the lessons using the system include all the essential features of inquiry and c) the use of the system effectively introduces teachers to the adaptation of inquiry based methods that simulate scientific methodology in the school classroom or laboratory.

Acknowledgments

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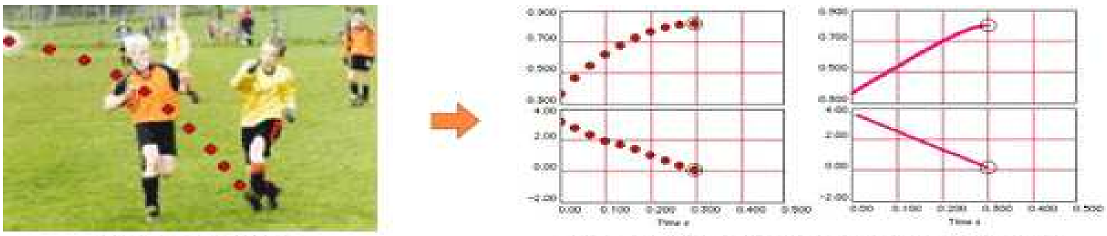
Figures to paper 2:



Data collection with an axion (accelerometer - GPS) embedded in a ball

The graphical user-interface is plotting data on a graph, creating a mathematical model to fit the data and relate the graph with the motions of the axions

Fig.1

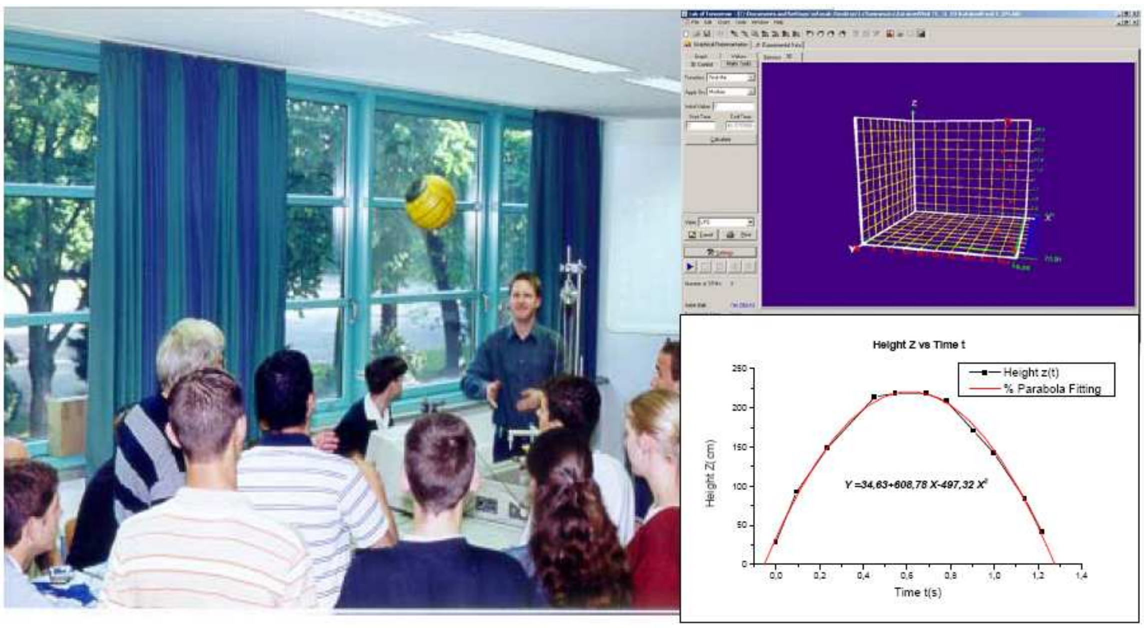


Fig.2

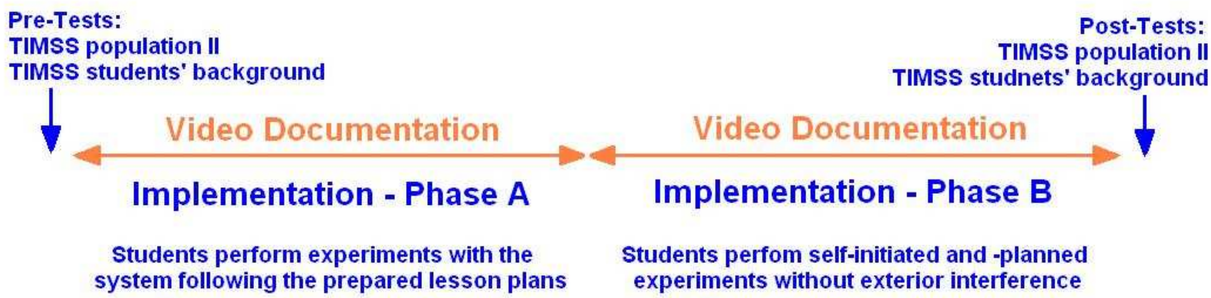

Pre-Tests:
TIMSS population II
TIMSS students' background
Post-Tests:
TIMSS population II
TIMSS studnets' background
Video Documentation
Video Documentation
Implementation - Phase A
Implementation - Phase B
Students perform experiments with the system following the prepared lesson plans
Students perfom self-initiated and -planned experiments without exterior interference

Fig.3

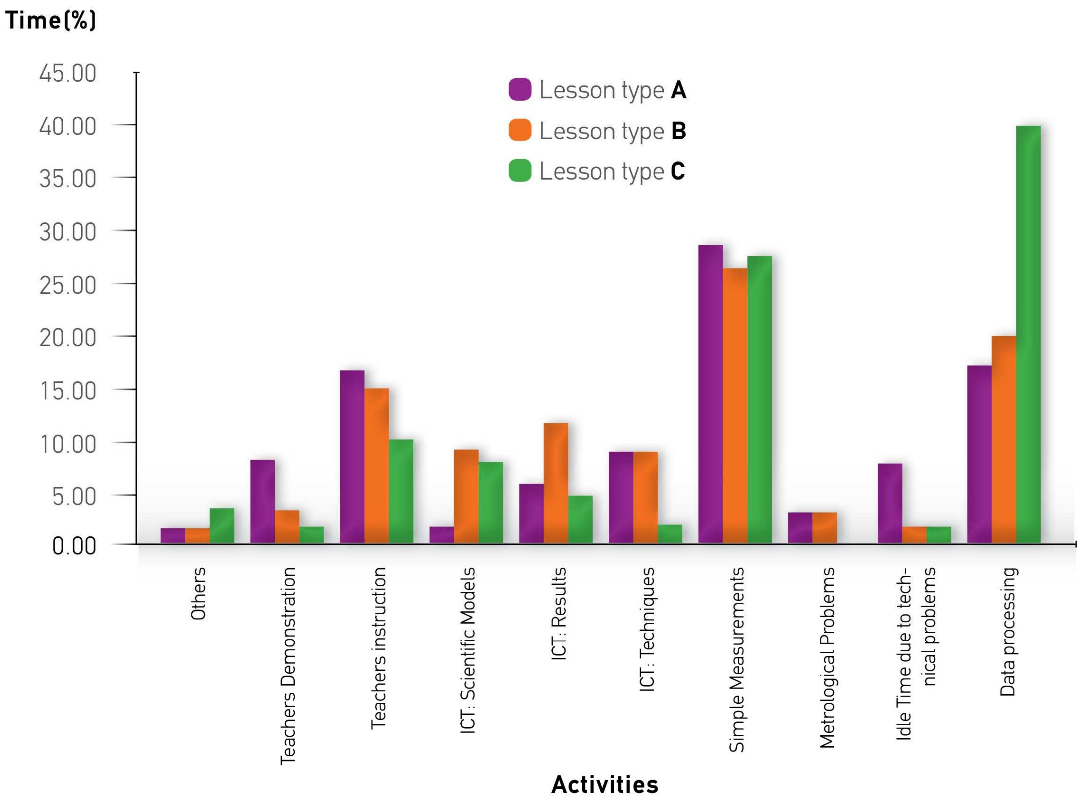

Time(%)
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Lesson type A
Lesson type B
Lesson type C
Others
Teachers Demonstration
Teachers instruction
ICT: Scientific Models
ICT: Results
ICT: Techniques
Simple Measurements
Metrological Problems
Idle Time due to tech-nical problems
Data processing
Activities

Fig.4

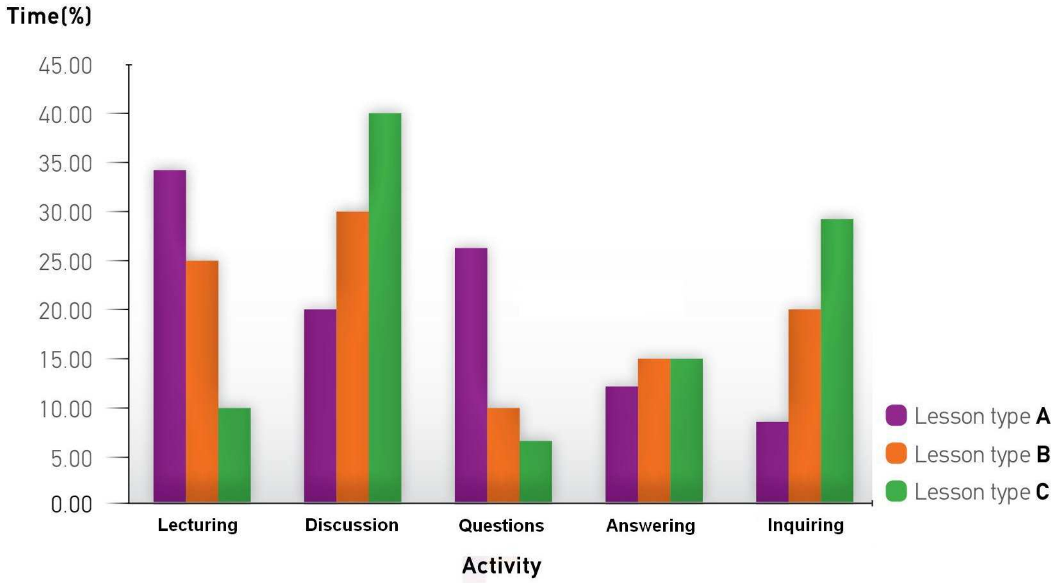

Time(%)
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Lecturing
Discussion
Questions
Answering
Inquiring
Activity
Lesson type A
Lesson type B
Lesson type C

Fig.5

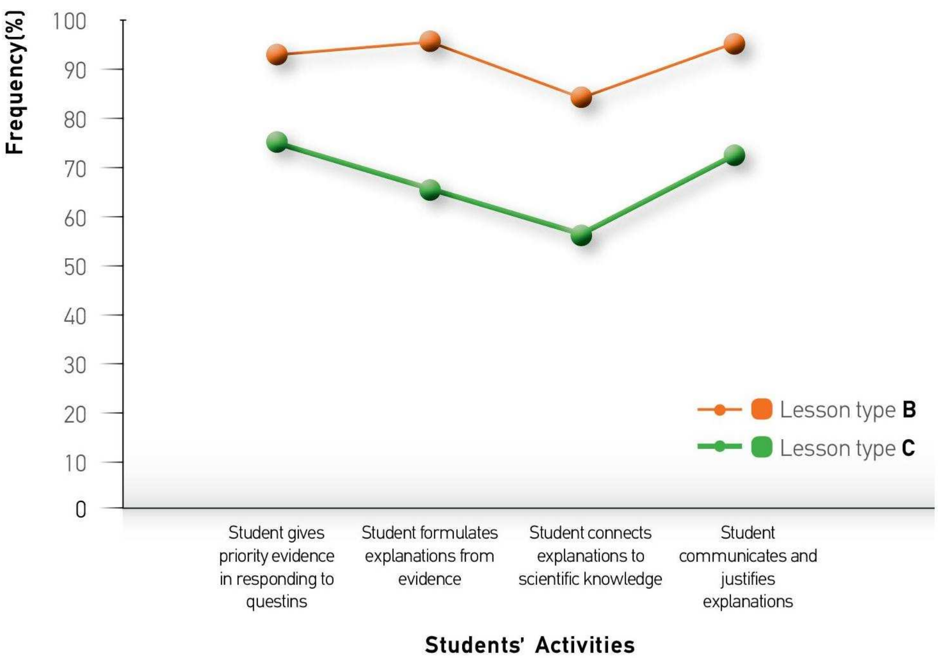

Frequency(%)
100
90
80
70
60
50
40
30
20
10
0
Lesson type B
Lesson type C
Student gives priority evidence in responding to questins
Student formulates explanations from evidence
Student connects explanations to scientific knowledge
Student communicates and justifies explanations
Students' Activities

Fig.6

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Visualizing the Invisible: Augmented Reality as an Innovative Science Education Scheme

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An innovative approach (which we labeled CONNECT) presents a pedagogical and technological mode cross-cutting the boundaries between schools and science centers as well as involving both students and teachers as playful learners. Learning pathways are offered to facilitate *in situ* learning by implementing an innovative educational environment provided by an augmenting technology mode (AR). This paper describes the educational and technical pathway setting and its implementation at a selected museum site as well as its relevant evaluation figures. The specific theme maintains the issue of a typical physics school content (of friction). Participation in the proposed activities positively influences students' intrinsic motivation as well as cognitive learning. Combining school science with students' activities in a science museum, as well as introducing advanced visualizations to a physical phenomenon, seems to make a substantial difference.

1. INTRODUCTION

Collaboration between schools and the informal learning sector is increasingly required when lifelong learning is emphasized. The value and utility of digital resources increasingly is discussed as contributing to an access to and a sharing with advanced tools, services, and learning resources by offering unique informal learning opportunities through the demonstration of a new method of interaction between visitor and exhibition.[1] lasting recent years, digital media have increasingly entered the science education field with the promise of adding substantial value.[2,3] Traditional media such as illustrated charts and audio guides together with interactive exhibits may take cognitive knowledge transfer to a new level of experience. Novel possibilities for the audience to experience conventional knowledge in an attractive way are arising out of this fusion. Therefore, the old-fashioned but still innovative vision of 'Museums of the Future' focusing on simple facts rather than on artifacts seems to come closer to reality.[4] Traditional science museums, with permanent collections, displayed in a historical context and thematic exhibitions, and new educational, interactive 'science centers' are encouraging a more diverse range of people to explore the various fields of scientific knowledge and their applications. Museums play an important role in facilitating lifelong learning, in terms of creative, cultural, and intercultural activity beyond any merely vocational aspects.[1,5] Lifelong learning, museums, and digital technologies share many of the same attributes, with the emphasis on learning from objects (rather than about objects) and on strategies from discovering information (rather than the information itself). The number of virtual visitors to many museums' websites had already overtaken the number of physical visitors on-site. These developments, both within the walls of an institution and outside, provide a number of challenges for educators and curators, at the heart of which lie the following questions: What is distinctive about learning in science museums and science centers? How might this specific change or evolve through the increasing use of digital technologies? These questions go to the heart of significant debates in this sector—how does learning in museums differ from or complement learning in schools? How can museums fulfill their potential to support lifelong learning? Should effort and money be spent primarily on the visitors who will enter into the institution or those who will virtually explore the site through the web? What is the role of objects in the process of learning with digital technologies? How does the relationship between museum educator and learner change as technologies are developed?

Augmented reality (AR) is about to join these developments. AR is characterized to simultaneously twin both virtual reality (VR) and real-world elements,[6] which makes it possible to combine real objects with virtual ones and to place information into real surroundings. Especially the possibility of AR to achieve convergence of education and entertainment is becoming more and more challenging as the technology is optimized and expands to other areas. Natural or historical events and characters, or to name a field outside of the strict science education reconstructed archaeological sites, could be simulated and augmented

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to the real world. AR is a booming technology attracting more and more attention from HCI (human computer interaction) researchers and designers. This allows the creation of meaningful educational experiences. As these experiences are grounded in a substantive subject area of knowledge, focusing on the intellectual and emotional development of the viewer, these AR learning environments possess both educational and entertainment value.

The CONNECT approach could provide a framework for a closer and more effective collaboration between science centers and schools. Our detailed approach has the science education school classroom as the point of reference. It is not aiming to bring the science center to school but to connect the different educational environments, keeping alive their strengths. In this framework the central research question of our study was the following: Under what conditions, if any, does the AR technology add value to science learning within the context of a school–museum program? In other words, under what conditions will an augmented field trip experience be better than a similar field trip experience without the advanced technology linking classrooms and science centers? To answer this question, we compared students who engaged with the AR versus students who did not, at each interactive exhibit. Experimental and comparison groups of students were studied. Students from both groups were exposed to previsit, visit, and postvisit activities, focusing on the particular interactive science exhibit. The only difference between these groups was that the experimental group used the AR, while the comparison groups did not. A variety of student outcomes were measured for both groups (using relevant quantitative and qualitative measures): student cognitive knowledge (specific site-specific knowledge tests) and student intrinsic motivation.

2. DESIGN AND PROCEDURES

2.1. Pedagogical Considerations

Amending the traditional scientific methodology for experimentation with selected visualization applications and specific model building tools will help a learner, in general, to articulate her/his mental models, make better predictions and reflect more effectively.[7] In addition, working to reconcile the gaps and inconsistencies within their mental models, system models, predictions and results will provide the learners with a powerful, explicit representation of their misconceptions and a means to repair them. Everyday experience suggests that students are eager to learn in informal settings such as outreach excursions to museums and science centers.[5] This positive attitude is believed to have two main roots: the freedom of leaving the framed formal setting of a conventional classroom and the students' positive motivation towards informal learning beyond the school to a real life setting where contextual knowledge occurs. In order to achieve the best results from informal education one has to take advantage of the motivating effects of freedom and physical context.[8] Our approach aims to bridge this divide, introducing new technologies and activities that fluidly link the use of physical materials with digital technology in creative enquiry and inventive exploration. Our aim is to demonstrate an innovative approach that cross-cuts the boundaries between schools, museums, research centers and science thematic parks, and involves students and teachers in extended episodes of playful learning. In most science-education settings, there is a sharp division between the physical and the virtual venue. Our work aimed to develop, test and evaluate learning schemes to be implemented in ambient, always available educational environments developed upon emerging technology in order to facilitate *in situ* learning, by maximizing the impact of information that is provided when the motivation of the student is highest.

While there is good reason to believe that informal learning experiences can enrich school science lessons relatively modestly, these experiences have been shown to add substantial value if specific conditions are provided, such as a sufficient integration into a school curriculum.[9] Supplementary research in science education should focus on how to effectively blend informal and formal learning experiences in order to significantly enhance the actual learning of science.[10] The CONNECT project bordered exactly on this area, by studying the twinning of school science education with science museum settings when acting as a catalyst for the professional development and enhancement of science teachers. It may substantially provide a framework for taking responsibility to 'bridge the gap' between science learning in science museums and in the school, through the use of CONNECT's technology and its 'connection' approach. Furthermore, the science teacher is an active member of the design team and plays a crucial role by using state-of-the-art technologies for science teaching. Also, the teacher is supported in the venture to create links with other schools and other science museums that are nearby or far away and hard to access. In addition, the CONNECT technology and approach (a) may help teachers to evolve from more traditional to more innovative teaching methods, (b) may use real-time visualizations to 'make the invisible visible' regarding the scientific phenomena which take place in interactive science exhibits, and (c) may 'bridge the gap' between the pedagogical and organizational frameworks of informal (museum) and formal (school) learning environments.

2.2. CONNECT Technology

In the framework of the CONNECT project, a personalized museum-wearable system along with a long series of informal educational scenarios was developed and simultaneously implemented, tested, and evaluated in science centers in selected museum sites all over Europe. The potential of such a system was shown by demonstrating that unique experiences to the visitors are offered, while at the same time the repertoire of learning opportunities is enriched and the blending introduced is helping to meet the challenge of 'science for all,' i.e., providing science education opportunities tailored to diverse and heterogeneous populations of citizens. These populations vary both in their interest in learning science and in their abilities to learn science. In parallel, it supports the provision of key skills to the future citizens and scientists (collaborative work, creativity, adaptability, and intercultural communication).

The innovative system, in extended episodes of playful learning, allowed a reasonable chance to learn and, upon informal education, to transcend from traditional museum visits to a 'feel and interact' user experience, allowing for learning 'anytime, anywhere,' open to societal changes and at the same time feeling culturally conscious (see also Fig. 1). These pedagogical concepts and learning practices address the implementation of a set of demonstrators (learning scenarios), employing advanced and highly interactive visualization technologies and also personalized ubiquitous learning paradigms in order to

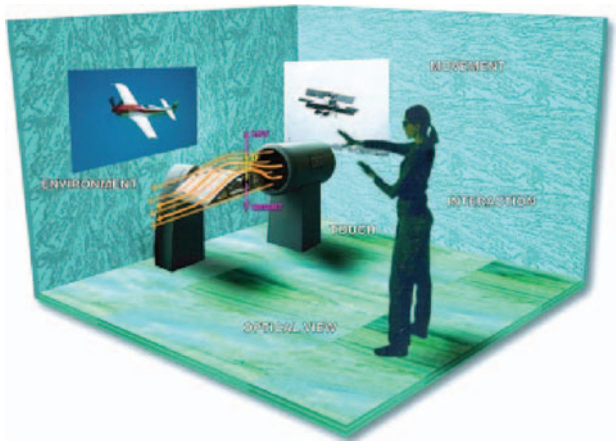

Fig. 1. System offers unique opportunities to a science museum and a science center visitor. A series of augmentations of physical phenomena, pictures, video, and text presents selected optical views, for instance, explaining the physical laws and phenomena under investigation.

Fig. 2. CONNECT science thematic park. The CONNECT experience could be realized by adding to the visitor's view a series of augmentations, advanced or simple. The advanced augmentations (e.g., forces, fields, microscopic view of the matter) are created by the museum team. Through an authoring tool the museum educator or the teacher can upload additional simple content in order to create more personalized scenarios.

enhance the effectiveness and quality of the learning process. In this way, the proposed service demonstrates the potential of the AR technology to cover the emerging need for continuous update, innovation, and development of new exhibitions, new educational materials, new programs, and methods in the approach to visitors.

The CONNECT project may take advantage of the fact that students enjoy visits to museums tremendously and that a resulting increased interest and enjoyment of science activities may constitute extremely valuable learning outcomes that actually may persist over time. The role of technology in bridging the still existing gap between formal and informal learning environments could be summarized in delivering scientific visualization and multimedia systems in the areas of virtual reality (VR) and AR. The possibility of AR and VR to achieve convergence of education and entertainment is becoming more and more challenging as the technology is continuously optimized and expanded to a wide area of applications. The CONNECT project may push the current boundaries further by providing a platform that integrates contextual information into classroom settings, employing advanced, highly interactive visualization technologies, embedded systems, and wearable computing. It has introduced new activities and personalized learning paradigms that fluidly link the use of, for instance, physical materials with digital technology in creative inquiry and inventive exploration.

The CONNECT project has developed an active learning environment, the virtual science thematic park (VSTP), functioning in two distinct and equally important modes from a pedagogical point of view: the museum mode and the school mode (Fig. 2). The VSTP allows for ubiquitous access to educational and scientific resources and incorporates all the innovative use of technology for educational purposes. The VSTP serves as a distributor of information, giving access to large databases, an organizer of suitable didactical activities such as conventional or virtual exhibit visits and/or 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.

The partnership is able to provide students with a variety of learning methods that incorporate experimental, theoretical, and multidisciplinary skills that will eventually enable them to become independent learners. The developed educational scenarios include field trips (virtual and conventional visits to science museums) that are tangential to the curriculum, pre- and postvisit curricular activities (including the use of internet resources), 'minds-on' experiments, and models of different kinds in everyday coursework heavily involving 'real' remotely controlled experiments in the 'student-friendly' and engaging environment of a thematic park or a museum.

The VSTP is able to provide single user and multiuser (for groups as large as a school classroom) support and includes two major components: (a) the mobile AR system which the visitor will wear during his/her real visit to a museum/science park and (b) the CONNECT platform which will facilitate the virtual visits of a remote classroom/visitor to a museum/science park (Fig. 3).

The mobile AR system is designed to provide 3D graphics superimposed on the user's field of vision together with other multimedia information, thus allowing 'extending' the real exhibits with virtual objects. This is particularly powerful for visualizing complex concepts in physics that are fundamental yet imperceptible (such as electric or magnetic fields, forces, molecular movements, etc.). Furthermore, it allows remote classes to observe, either on-line or off-line, the activities during the visit to the science museum/park (see Fig. 4). The mobile AR system consists of several hardware devices. These include a wearable processing unit (heart of the system), personal display units (optical see-through glasses) to project/embed virtual 3D objects onto the real exhibit environment, tracking sensors to determine the visitors' exact location and orientation (six degrees of freedom), video cameras for recording the students' learning activities and the exhibit augmentation, human interface devices (microphone and headphones for real-time interaction with the exhibit and the remote classroom), and the transmission module to the mainframe computer in order to stream the augmented view to the CONNECT platform.

Furthermore, the mobile AR system is supported by a multiplicity of software tools, such as recognition (tracing and identification) of individuals, groups and objects, a user friendly audiovisual interface to allow interaction with virtual objects and to interpret the learning scenario descriptions, natural language and speech interfaces for audio communication, reflexive learning

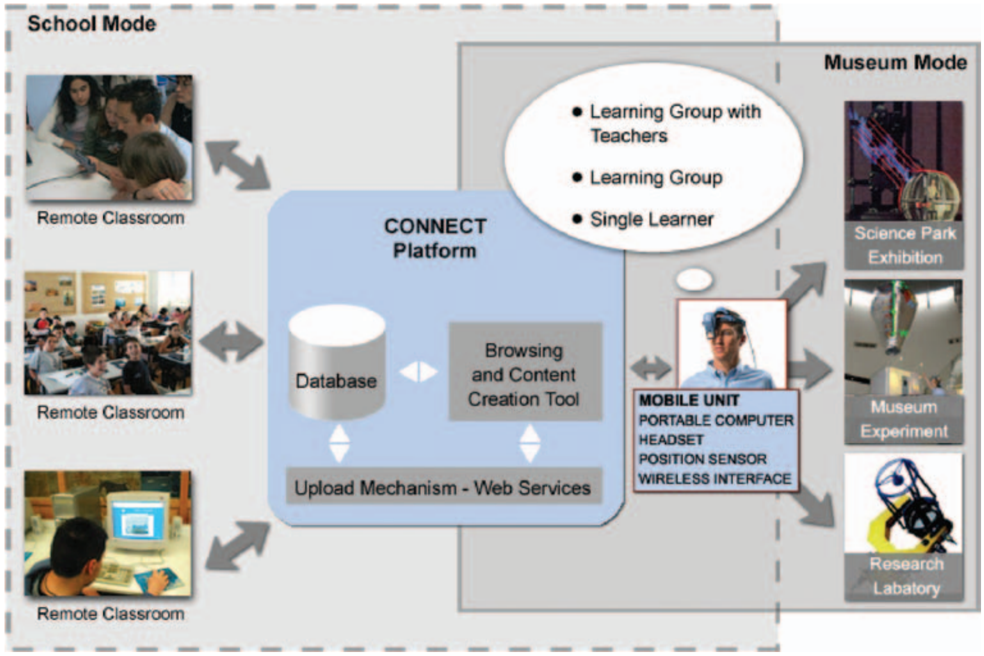

Fig. 3. General architecture of the CONNECT system.

systems (adaptable and customizable) for reviewing experiences, content design facilities, simulation, and visualization aids.

2.3. CONNECT Platform

The purpose of the CONNECT platform is to provide
(i) teachers with tools in order to facilitate students' learning through managing third-party objects, thus making relevant instructional materials accessible in order to enhance the museum exhibits. As such, the platform is a content management system,
(ii) students with a web site which will support innovative learning using the AR system,
(iii) the AR system with a structured file containing objects and applications to be displayed during the real visit to the museum,
(iv) schools with the means to communicate and to observe museum visits, either real-time or recorded, and
(v) museums and science centers with the means to manage their exhibit augmentations.

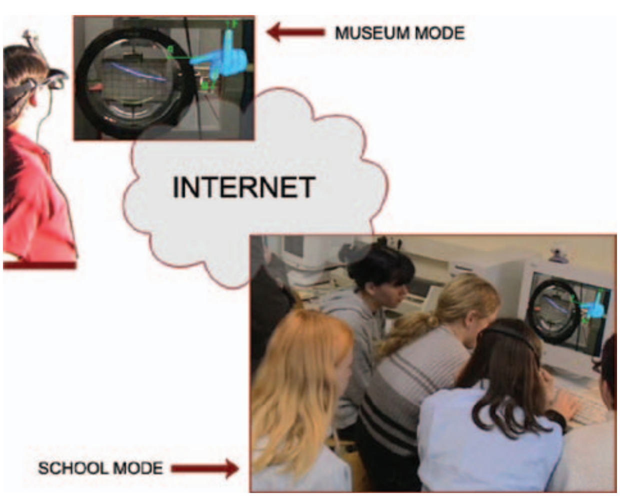

Fig. 4. Two modes of operation of the CONNECT system. The system supports both on-site learning and on-line learning, giving access to a variety of resources and collections even to communities well beyond the walls of the science museum, who for geographical, social, or historical reasons will never enter the hallowed halls.

The CONNECT platform thus composed of several components includes specialized and generalized web services, browsing and content creation tools, and a multimedia knowledge database. The role of a content creator is to provide educational presentations (scenarios) of the pathways that different students can follow. These presentations can be thought of as interactive films where the part of the film that is presented to the student depends on where the student is located and on what their interactions with the system are. In order to facilitate the content creator in entering, editing, or assembling and dissembling new media objects into meaningful presentations, knowledge management tools enable a knowledge database to be built and managed, which provides for persistency, coherence, and data integrity. Archiving, cataloguing, and indexing tools are employed for the creation of the knowledge repository contents. The CONNECT platform maps the design artifacts into code in an object-oriented language, supporting the mobile's AR system specifications and functionalities. The standards and the information that the mobile AR system uses to transact with the CONNECT platform specify the types of 'data objects' which will be stored in the database. These 'objects' provide the communication and interaction of the CONNECT platform with the users of the mobile AR system. Furthermore, the developed system guarantees the required efficiency in terms of access speed (for real-time scheduling of the application processes) and available bandwidth (for real-time video–audio communication between the AR user and the remote classroom).

2.4. Implementing CONNECT

Besides other implementations, the CONNECT approach and technology has been used in different phases of work for

Fig. 5. Visualizing the invisible: example of visual augmentation (see both inserts).

evaluation purposes (technological and pedagogical), so that teachers, students, and museum educators receive direction about the project and its technological and pedagogical results. In the framework of this paper, we focus on the specific activities with the AirTrack. The CONNECT approach included three main sets of activities for the participating teachers and students.

Pre-visit phase: The teacher presented to the students the physical phenomenon issue under study. This was seen as an important piece of implementation, since any cognitive achievement builds better upon prepared minds.

Visit phase: The teacher demonstrated the phenomenon through the use of AR. Students interacted with the exhibit by conducting the selected experiments, e.g., the effect of airflow on the moving object (see Fig. 5).

Post-visit phase: Back in the classroom, the teacher and students discussed and analyzed their experiences in depth and the teacher carried out the lesson according to the curriculum plan. The actual exhibit demonstrated that friction is present when two surfaces are in contact, thus realizing a common occurrence in our everyday lives. For example, it allows us to walk or run and is necessary for the motion of wheeled vehicles. Experimentally, we can find friction as being proportional to normal force. It takes a greater force to start an object moving than it does to keep it going once it has started sliding. Therefore, static friction is greater than kinetic friction. The concept of friction is a compulsory national curriculum topic in science education in most countries. The exhibit can also be further incorporated into a broader thematic area of learning about forces, such as Newton's laws, elastic/inelastic collisions, or mechanical oscillations. The exhibit demonstrates a cart sliding on an air track, under the influence of an external horizontal force. It is possible to blow air through tiny holes on the surface of the AirTrack to reduce friction and thus facilitate the cart's motion. Carts of different weight are available. By experimenting with this exhibit, students learn about the laws of motion, investigate the nature of frictional forces, and can deduce the law of friction. The AirTrack is a regular exhibit of a science and technology museum.

Two groups of students participated in the implementation: in the experimental group, classes interacted with a visually augmented exhibit, and in the comparison group, classes interacted with the same exhibit but without any advanced visualizations. Both groups used the same learning scenario, demonstrating balanced and unbalanced forces on an object combined with the effect of airflow on friction. The research questions in our survey focused on the extent that the CONNECT technology adds value to the science museum visit experience. Altogether, 119 students (15–16 years old) from conventional schools participated in the implementation. The concept of friction was the main theme of the implementation. Teachers were familiarized with the CONNECT platform before the museum visit; they were also aware of the approach of developing pathways for their students. All students were questioned twice, with the same item set. However, they never were aware of any monitoring schedules in advance in order to avoid any specific preparation or hidden learning effects.[11]

The concept under study (friction) is part of the school curriculum of the participating students. Before the actual implementation phase at the exhibit, an introductory lesson in the classroom provided the teaching about the laws of friction and the concept of friction. Usually, the class work began with a question given to the students that required an individual answer in their notebook before discussing this issue with their peers. After the group discussion, the students had to agree to a common group response and to prepare a class presentation for general discussion. Class discussions were common and all students could participate. Students asked questions to a group representative or made comments in order to clarify or challenge the answer proposed by his/her group. The discussions focused on an answer to the initial question accepted by all. However, often there were unresolved disagreements among peers and, thus, an experiment to provide an objective answer to the problem being investigated. Students' prior knowledge and their particular difficulties in understanding the different concepts and explanations of phenomena guided both the selection of the content and the instructional interventions. We have argued that students operate on the principle of a naive theory of physics constructed on the basis of their everyday experience and acting as a constraint in the acquisition of scientific knowledge. In the case of phenomena of mechanics, recent research unveiled high school students' beliefs about force as an acquired property of inanimate objects when explaining movements.[12–15] According to this acquired force model, also known as the impetus misconception in the literature, force is the agent that causes an inanimate object to move. The object stops when this 'acquired force' dissipates in the environment. These characteristics of force very often make students conflate force with energy, and this makes it difficult for them to understand the scientific explanation of motion. Some common misconceptions about friction are the following: Friction cannot act in the direction of motion. Friction always hinders motion, therefore, a reduction of friction is always desired. Friction always converts mechanical energy to thermal. A force applied, by, say, a hand, acts on an object even after the object leaves the hand. The force of gravity or weight is what keeps things stationary or what decelerates moving objects. We can have friction even if objects are not in contact.

In order to help students construct the scientific representation of the concept of friction force, the 'friction model' was introduced in class before the visit. This model was introduced after the students had already experienced how the hardness of different surfaces affects the motion of the objects that slide on them. At this point the teacher asked the students to explain the fact that even the polished smooth surface of the top of a table hinders the motion of the objects moving on it. Then, the teacher presented to them slides with photographs of glass surfaces magnified by an electronic microscope as a proof that even the smoothest surface has anomalies that cause the appearance of friction forces. After a short discussion at class level about how these anomalies of the surfaces can hinder the motion of objects, the teacher presented to the students the 'friction model.' A situation of cognitive conflict was used in certain situations to make the students realize that their explanatory framework could not explain some empirical results. The teacher challenged students' beliefs that in order to make an object slide on the ground a force must be exerted on the object that is greater than its weight. In this model, weight is considered as an inborn asset of an object and not as an interaction between the earth and the object. Students were asked to test their predictions using different objects and dynamometers to compare the weight of the objects and the magnitude of the force that makes the objects slide on different surfaces. Students were surprised to see that the forces exerted were always smaller than the weight of the objects. This created a strong motivation for them to seek the scientific answer. Through carefully selected activities the students realized that the motion of the object is affected by the hardness of the surface on which the object slides, and thus they approached the concept of friction force.

3. RESULTS AND DISCUSSION

In the cognitive knowledge test (see Fig. 6) students in the experimental group significantly outperformed students in the comparison group. Specifically, the AR visualizations were shown to help students in the experimental group to correct some common misconceptions. There are several studies that refer to students' alternative ideas about the concept of friction.[16–19] The data from all surveys demonstrate that the majority of students believe that 'friction does not occur if there is no movement between surfaces' and that 'friction is a constant force.' The current survey verifies these results (Fig. 7). Of the students who participated in the CONNECT survey, 73% selected the graph on the left as the correct answer to question 2 in the pretest, as they believed that there is no friction as there in no motion. Their ideas changed dramatically after the AR demonstration. Of the students who participated in the experimental group, 91% correctly answered the same question in the posttest. In addition, it can be seen that the deviations from the average score were minimized after the experience of the AR-enriched field trip due to the fact that the innovative character of the technology, as well as the visualization techniques used, have increased the students' interest and

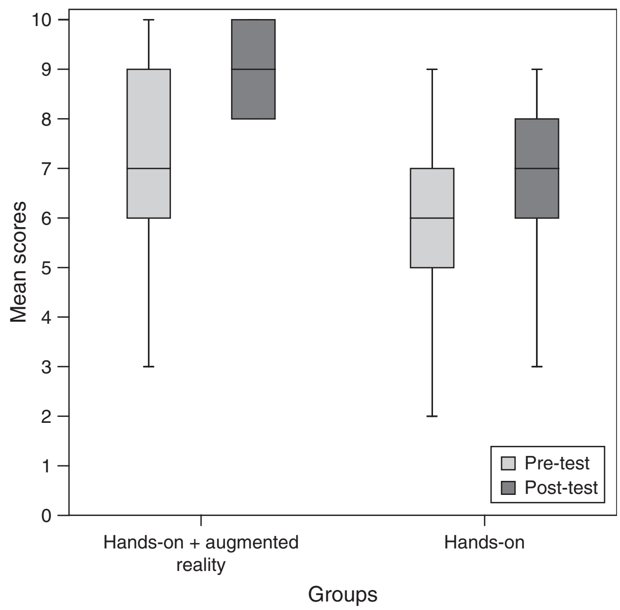

Fig. 6. Knowledge achievement in the experimental and comparison group. Students in the experimental group significantly outperformed students in the comparison group.

motivation to focus on the phenomena under investigation. This result could be combined with the motivation measurements presented in Figure 8.

Motivation was measured by using the intrinsic motivation inventory.[20, 21] This established questionnaire battery targeted the learning activity directly and, hence, was administered shortly after the students' museum visit. The selected subscales are enjoyment/interest (7 items), competence (7 items), and effort (5 items). To ensure reliability of the translated questionnaires, reliability tests have been conducted and a rigid translation procedure has been followed. Regarding motivation, students in the experimental group showed significantly higher scores for interest and enjoyment; they also gave the AR-enhanced exhibit a higher value on usefulness and value than the comparison students (see Fig. 8). In particular, after an interaction with the AR approach, the experimental group found the augmented exhibit to be more important, more essential, and more encouraging of student teamwork than the comparison group. Hence, we may tentatively argue that, based on these data, the students feel that the technology adds a dimension of importance and seriousness to the exhibit and to the science center visit. It is also very important to state that the students seemed to recognize the interconnections between the issues discussed and presented during the field trip and the relevant issues of their normal lesson.

The subscale of Effort/Importance did not differ between the two groups. The students appeared to recognize the importance of the proposed educational activities (both with and without the use of technology), while the fact that the students in the experimental group did not consider that extra effort is needed to work with the AR system possibly demonstrates that it is a rather user-friendly tool. It is also interesting to note that twice as many students in the experimental group asked questions than in the comparison group and over 30% of these students asked advanced questions (e.g., 'Would the glider move and stop, if we turn on and off the airflow?'). The students were

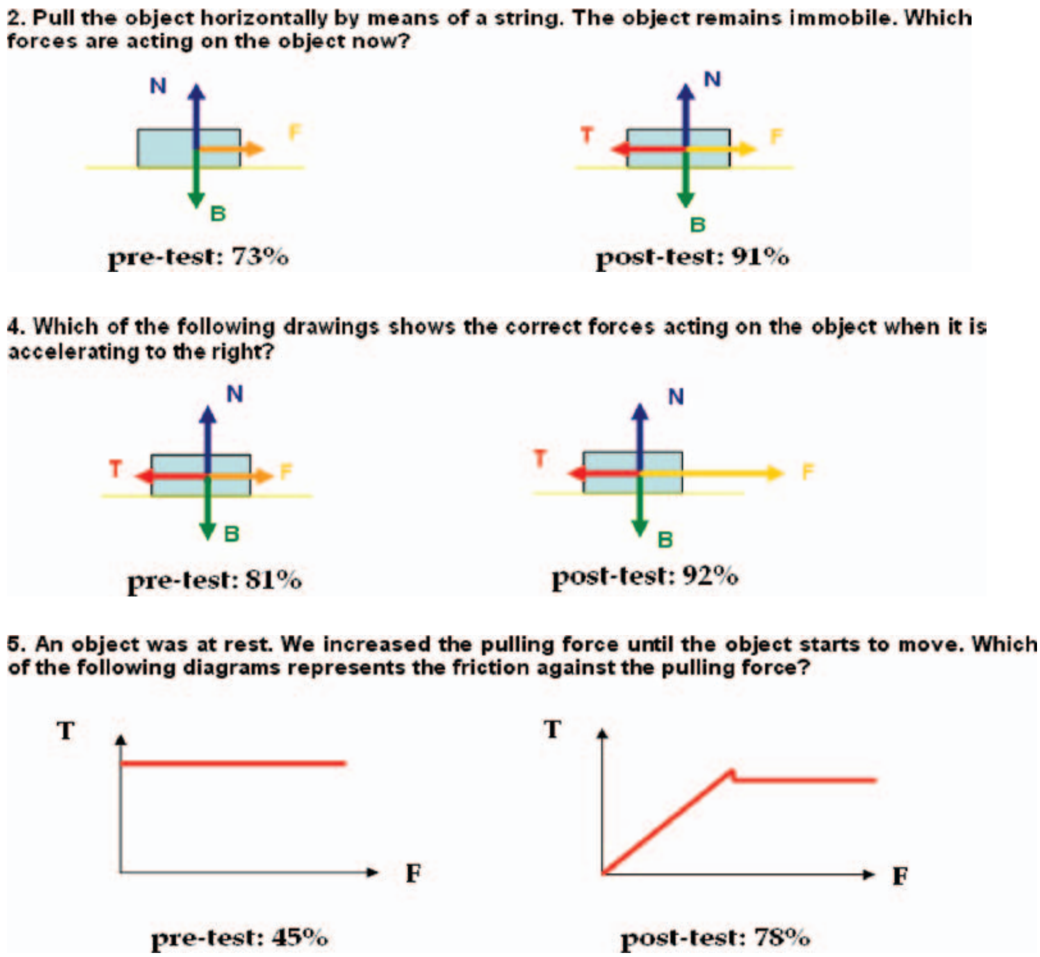

Fig. 7. Of the students who participated in the CONNECT survey, 73% selected the graph on the left as the correct answer to question 2 in the pre-test as they believed that there is no friction as there in no motion. Their ideas changed dramatically after the AR demonstration. Of the students who participated in the experimental group, 91% correctly answered the same question in the posttest. In addition, the results from questions 4 and 5 demonstrate that the initial belief that friction is a constant force changed dramatically after the AR demonstration.

particularly intrigued with the ‘dynamic visual graphics’ of the AR technology. The teachers were also very positive about the AR technology.

A similar study based on the same AR technology, recently presented by Sturm and Bogner,[22] investigated the effect of an augmented reality approach on an aerofoil exhibit using the same measurement instrument approach. Multiple choice tests implemented a week before and immediately after experimenting with the aerofoil exhibit monitored the learning outcome of the students: Surprisingly, only the hands-on group with no AR-appliance added significantly new knowledge but the experimental group using the AR-technique did not. However, the students in the experimental group reported an overall higher motivation than the comparison group. The authors explained their results in terms of the cognitive load theory, which is, a consistent overloading the involved students prevented any learning. Educational implications drawn out of this study clearly highlighted the implementation of the new technology in science education but cautioned the risks especially when low achieving students are involved.

The fundamental question that arises from these results is: Under what conditions did AR technology make a difference? In discussing this question, based on the evaluation findings reported above, we can conclude that these conditions are connected to four related domains:

(i) the AR technology, graphics and scenarios,
(ii) curriculum integration,
(iii) the teacher’s role and perspective, and
(iv) the students’ experience of the AR.

Our findings suggest that the CONNECT approach, which focuses on the use of AR technology during a science center–school program, provides added value to science learning. We believe that our findings allow the presumption that this value-added contribution of the CONNECT approach derives from two central factors: (a) increased student experimentation and (b) increased student interest. In other words, we argue that, under the conditions identified and described above, the AR technology can function to provide a stronger context for student investigations and for the development of student interest than the traditional field trip. We suggest that the AR-related features that are responsible for these differences include the opportunity for students to make more precise measurements, a deeper personal experience with the scientific phenomenon (as a result of increased experimentation), and AR graphic visualizations of the unseen but vital factors. Our data support the argument that

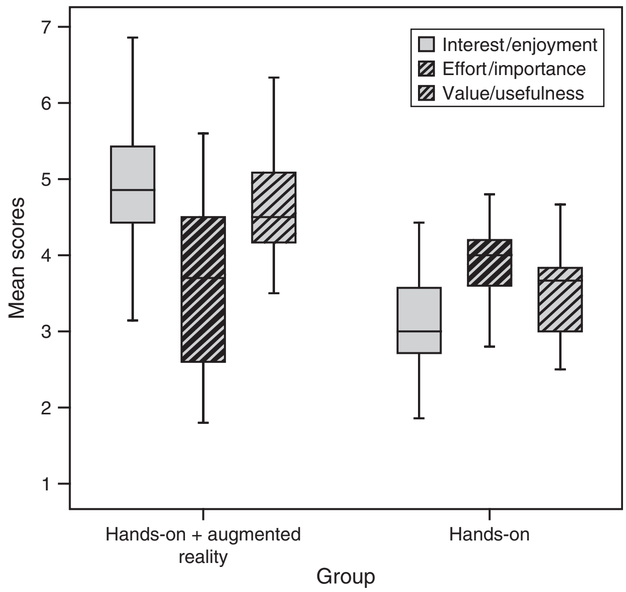

Fig. 8. Regarding motivation, students in the experimental group showed significantly higher scores for interest and enjoyment; they also gave the AR-enhanced exhibit a higher value on usefulness and value than the comparison students. The subscale of effort/importance did not differ between the two groups, demonstrating the user friendliness of the proposed approach.

learning involves (a) student knowledge gain, (b) increased student motivation and attitudes, and (c) improved student investigation skills. These three aspects were mentioned as the three basic 'goals of learning' by the participating science teachers and they also represent the 'criteria of success' for successful science center–school partnerships. In the framework of the study, the schools were able to devote more time to the first goal (knowledge gain). Owing to the authentic context of the exhibits and AR technology, the science center experience contributed a great deal to the achievement of the third goal (increased motivation and positive attitudes). In addition, by focusing on the achievement of the second goal (student investigation skills), via the AR-mediated visualizations and measurements, the proposed approach helped to provide a 'common agenda' for the student work in the two contexts. Combining school science with students' activities in a science center, as well as introducing advanced visualizations to a physical phenomenon, appears to make a difference. Students have the chance to relate their actions on the exhibit to the changes of forces applied on the cart. As they manipulate the cart, the representations of forces are updated accordingly to support their understanding and scaffold their thinking. Therefore, visualizing the applied forces provides students with links between real-life exploration of the AirTrack exhibit and abstract representations of the physical phenomena it presents.

4. OUTLOOK

By making the invisible visible, the CONNECT intervention helped students to face contradictions between their own beliefs and their science textbooks. Informal education remains an indispensable extension of school activities, which undoubtedly helps to advance a student's sparkling coefficient. Students may transcend traditional classroom-based teaching to a 'feel and interact' student experience that allows for learning 'anytime, anywhere.' Furthermore, through the CONNECT experience, the teacher is creating links between the students' own experiences and the learning content; they add value to the conventional field trips through the previsit and postvisit activities held in the classroom. In more detail, the teacher has a specific role to play in this 'bridging the formal with the informal': they are the decision maker in *what* type of advanced visualization is to be presented *when* and *where* in the student's view, through the teacher's authoring tool (CVD). Such a decision can be based on the library that exists in the authoring tool or in additional types of simple content (e.g., texts, photos, videos, audios) that can be uploaded by the teacher. In such a way, the teacher becomes an active designer of a state-of-the-art learning environment that they can shape according to their own and their class's needs. Furthermore, such decisions make them a valuable contributor to the shaping of the student's experiences: they not only rely on information provided *to* them but rely on information provided *by* themselves. Therefore, the teacher can put effort into tailoring the environment to their lesson and satisfy students' curiosity for understanding the world around them.

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Chapter 14
Visualising the Invisible in Science Centres and Science Museums:
Augmented Reality (AR) Technology Application and Science Teaching

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ABSTRACT

This chapter presents an implementation of augmented reality (AR) technology in science education. While this technology up to now mainly was used by very special users such as the military and high-tech companies it gradually converts into wider educational use. Specific research programmes such as CONNECT and EXPLOAR applied this technology with a specific focus on selected learning scenarios by a close co-operation of formal education and informal learning. Empirical effects related to intrinsic motivation and cognitive learning of students (n: 308) were encouraging. The implementation of augmented reality in the context of the "Hot Air Balloon" exhibit at Heureka science centre in Finland unveiled encouraging results. While the high achievers again did best in the post-knowledge test, low achievers again were clearly catching up with the others. The difference to between the treatment and the control group was clear. It seems like that visualising a very theoretical scientific phenomenon increased the individual understanding substantially especially for those students who otherwise had severe difficulties. This is an essential result which needs further analysis. The "new educational model & paradigms" was monitored for 182 teachers. The main focus, however, pointed to a feed-back of in-service teachers and teacher students since they act as key players in the use and acceptance of any new educational technology or curriculum renewal. The main objectives were as follows: (i) From a teacher-controlled learning towards a pupil-orientated learning; (ii) connecting of ICT-AR with and between existing learning environments; and (iii) changes in roles and responsibilities of students and teachers.

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INTRODUCTION

Museums of the past sought artifacts, museums of the future will show facts

Otto Neurath
Museums of the future
Survey Graphic, 1933

Schools and the informal learning sector increasingly collaborate and provide an increasing value for lifelong learning combined as well as they contribute to the debate over values and utilities of digital resources. This debate includes an access to and a sharing of advanced tools, services and learning resources, whether it offers unique informal learning opportunities to visitors of science museums and science centers through its demonstration of a new method of interaction between a visitor and an exhibition. Over the last years digital media has increasingly entered the field of museums and science centers. Traditional media such as illustrated charts and audio guides together with interactive exhibits take the knowledge transfer to a complete new level of experience. The "Museums of the Future" of Neurath & Cohen (1973) focusing on facts rather on artifacts seems to come very close to this view. In their different ways, traditional science museums - with permanent collections, displayed in a historical context, and thematic exhibitions - and educational, interactive "science centres" are encouraging a more diverse range of people to explore the various fields of scientific knowledge - and their applications. Museums have an important role to play in facilitating lifelong learning, in terms of creative, cultural and intercultural activity beyond any merely vocational aspects. Lifelong learning, museums and digital technologies share many of the same attributes, with emphasis on learning from objects (rather than about objects) and on strategies from discovering information (rather than the information itself).

Since a few years, the number of virtual visitors to many museums' websites had already overtaken the number of physical visitors on-site (Hin, Subramaniam & Meng, 2005; ASTC 2009). These developments, both within the walls of the institution and outside, provide a number of challenges for educators and curators, at the heart of which lie the questions – what is distinctive about learning in science museums and science centres, and how might this change or evolve through the increasing use of digital technologies? These questions go to the heart of significant debates in this sector – how does learning in museums differ from or complement learning in schools? How can museums fulfil their potential to support lifelong learning? Should effort and money be spent primarily on the visitors who will enter the walls of the institution or those who will virtually explore the site through the web? What is the role of objects in the process of learning with digital technologies? How does the relationship between museum educator and learner change as technologies are developed?

Augmented Reality (AR) is about to join the described developments. With AR it is possible to combine real objects with virtual ones and to place suitable information into real surroundings. The possibility of AR to make convergence of education and entertainment is becoming more and more challenging as the technology optimises and expands to other areas. Natural or historical events and characters, reconstructed monuments or archaeological sites could be simulated and augmented to the real world. AR is a booming technology which attracts more and more attention from HCI (Human Computer Interaction) researchers and designers. This allows the creation of meaningful educational experiences. As these experiences are grounded in a substantive subject area of knowledge, they focus on the intellectual and emotional development of the viewer; therefore, AR learning environments have possession of both, educational and entertainment value.

The EXPLOAR service is the main outcome of the European CONNECT (www.ea.gr/ep/connect) which developed a personalized museum wearable system along with a long series of informal educational scenarios. The system was implemented in science centres in UK, Sweden, Greece and Finland (Sotiriou et al. 2007) which demonstrated the potential of such a system to offer unique experiences to the visitors. Similarly, the enrichment of the repertoire of learning opportunities as well as the blending helped to meet the challenge of "science for all", i.e., it provided science education opportunities tailored to diverse and heterogeneous populations of users. These populations vary both in their interest in learning science and in their abilities to learn science. In parallel it supports the provision of key skills to the future citizens and scientists (collaborative work, creativity, adaptability, intercultural communication).

The EXPLOAR service demonstrates a suitable example of an innovative approach involving visitors in extended episodes of playful learning. The EXPLOAR service specifically uses informal education as an opportunity to transcend from traditional museum visits, to a "feel and interact" user experience, by allowing a learning "anytime, anywhere", an openness to societal changes and at the same time a feeling culturally conscious. These pedagogical concepts and learning practices would address implementing a set of demonstrators (learning scenarios), employing advanced and highly interactive visualization technologies and also personalised ubiquitous learning paradigms in order to enhance the effectiveness and quality of the learning process. In this way, EXPLOAR demonstrates the potential of the 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.

The CONNECT system provided the starting point to the EXPLAR approach. It consisted of an joint initiative of pedagogical, cognitive science and technological experts, museum educators and psychologists who searched for possibilities of using advanced technologies for educational purposes. The Virtual Science Thematic Park was It was developed as an active learning environment that functions in two distinct and equally important, from a pedagogical point of view, modes: the museum mode and the school mode. It allows for ubiquitous access to educational and scientific resources and incorporates all the innovative use of technology for educational purposes. The partnership has provided a variety of learning methods incorporating experimental, theoretical and multidisciplinary skills that will eventually may produce independent learners. The developed educational scenarios included field trips (virtual and conventional visits to science museums and parks) that are tangential to existing curricula, to pre- and post-visit curricular activi-

Figure 1. The EXPLOAR service offers unique opportunities to a science museum and a science centre visitor. A series of augmentations of physical phenomena, pictures, video and text are presented to the optical view of a user while explaining the physical laws and phenomena under investigation. The system also supports the work of the exhibition design and development team of a museum as it allows for enrichment of current exhibits with numerous applications and gadgets providing an easy way to update and to renovate each exhibition.

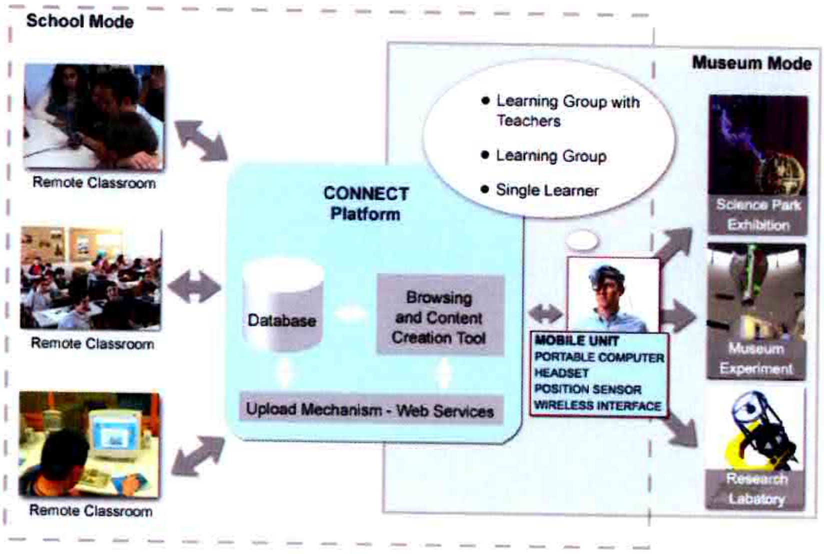
Figure 2. Visualizing the invisible: The CONNECT Science Thematic Park.The CONNECT experience may add to a visitor's view a series of augmentations, both, advanced or poor and simple. The advanced augmentations (E/M fields, molecular motions, microscopic view of the matter) were created by the CONNECT team. Through an authoring tool the museum educator or the teacher can upload additional simple content in order to create more personalized scenarios.

ties (including internet resources), to 'minds-on' experiments and models of different everyday coursework involving 'real' remotely controlled experiments. Altogether a "student-friendly" and engaging environment of thematic parks or museum are provided.

The working hypothesis of the CONNECT project was that the amendment of the traditional scientific methodology for experimentation with visualization applications and model building tools will help a learner to generally articulate mental models, to make better predictions and to reflect more effectively. The project took advantage of the fact that students enjoy tremendously visits to museums which often increases individual interest scores and enjoyment of science activities as well as constitute to valuable long-term learning outcomes (Ayres & Melear, 1998). The role of technology in bridging the gap between formal and informal learning environments may sum up to the delivery of scientific visualization and multimedia systems in the areas of virtual (VR) and augmented reality (AR). The possibility of AR and VR to make convergence of education and entertainment is becoming more and more challenging as the technology is continuously optimised and expands to a wide area of applications. The CONNECT project has pushed the current boundaries further by providing a platform that integrates contextual information into classroom settings, by employing advanced, highly interactive visualization technologies embedded systems and wearable computing. Simultaneously it has introduced new activities and personalized learning paradigms that fluidly link the use of physical materials with digital technology in creative inquiry and inventive exploration.

The main technological innovation of CONNECT consisted in the development of an advanced learning environment, the Virtual Science Thematic Park (VSTP). It was supposed to act as a main "hub" of all available resources within the existing network of science parks, science museums and research centres. The VSTP serves

Figure 3. The general architecture of the CONNECT system.



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. Additionally it interconnects all the members of the network, by allowing for ubiquitous access to educational and scientific resources to students, teachers and users in general from all around Europe.

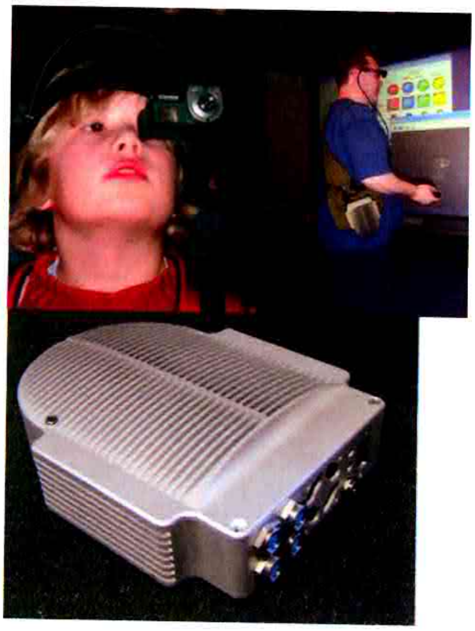
The Virtual Science Thematic Park provides support for single and multi-user (for groups as large as a school classroom) and it includes two major components (a) the mobile AR system which the visitor used during his/her real visit to a museum/science park and (b) the CONNECT platform which facilitated the virtual visits of a remote classroom to a museum/science park.

The Mobile AR System

The mobile AR system (figure 4) was designed to provide 3D graphics superimposed on the user's field of vision together with other multimedia information. Thus, it allowed to "extend" a real exhibit with virtual objects. This is regarded as a particularly powerful tool for visualizing complex concepts in physics that are fundamental yet imperceptible (such as electric or magnetic fields, forces, etc). Furthermore, it allowed for remote classes to interact, either on-line or off-line, with a visit to a science museum/park. The mobile AR system consisted of several hardware devices, including: a wearable processing unit (heart of the system), personal display units (optical see-through glasses) to project/embed virtual 3-D objects onto the real exhibit environment, tracking sensors to determine the visitors' exact location and orientation (six degrees of freedom), video cameras for recording the students' learning activities and the exhibit augmentation, human interface devices (microphone and headphones for real-time interaction with the exhibit and the remote classroom) and the transmission module to the mainframe computer in order to stream the augmented view to the CONNECT platform.

Furthermore, the mobile AR system was supported by a multiplicity of software tools, such as recognition (tracing and identification) of individu-

Figure 4. The mobile AR system. © 2007 Heureka, Used with Permission.



als, groups and objects, a user friendly audio-visual interface to allow interaction with virtual objects and to interpret the learning scenario descriptions, natural language and speech interfaces for audio communication, reflexive learning systems (adaptable and customizable) for reviewing experiences, content design facilities, simulation and visualization aids. The purpose of the CONNECT platform.

Teachers could implement tools for facilitating a student's learning through managing third party objects. Thus, he/she made relevant instructional materials accessible in order to enhance the museum exhibits. The mediator within this networking was the platform of the Content Management System. Students were supported by an innovative learning using the AR system which contained objects and applications to be displayed during the real visit to the museum. Schools could communicate and observe museum visits, either real-time or recorded. Museums and Science centres were in charge to manage the specific exhibit augmentations.

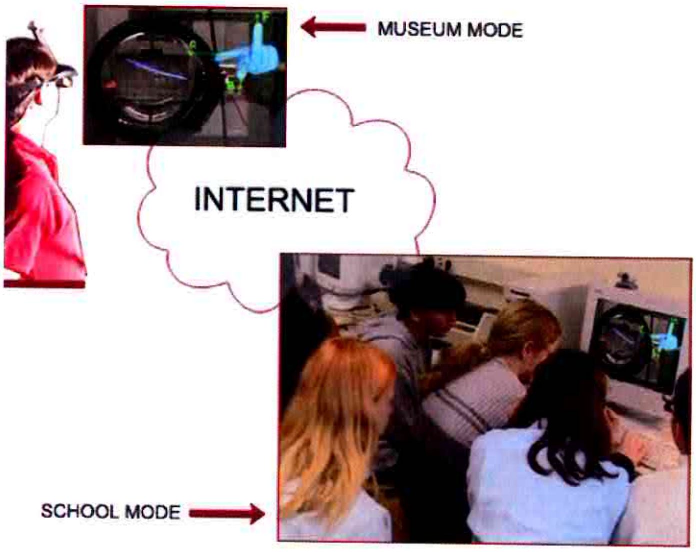
The CONNECT platform was composed by several components, including specialized and generalized web-services, browsing and content creation tools and a multimedia knowledge database. The role of the content creator of the system consisted of the provision of educational presentations (scenarios) where different pathways could be followed. These presentations could consist of interactive movies, where the part of the movie that is presented to the student depends on where the student is located, on what his/her interactions with the system are. In order to facilitate the content creator in entering, editing or assembling and dissembling new-media objects into meaningful presentations, knowledge management tools allow to build and manage a knowledge database, allowing for persistency, coherence and data integrity. Archiving, cataloguing and indexing tools were employed for the creation of the knowledge repository contents.

The CONNECT platform maps the design artefacts into an object-oriented language code, supporting the mobile's AR system specifications and functionalities. The standards and the information that the mobile AR system uses to transact with the CONNECT platform specify the types of "data objects" which were stored in the database. These "objects" provided the communication and interaction of the CONNECT platform with the users of the mobile AR system. Furthermore, the developed system guaranteed the required efficiency in terms of access speed (for real-time scheduling of the application processes) and available bandwidth (for real-time video-audio communication between AR user and remote classroom).

Learning in Science Museums and Science Centres: Need for Interactivity and Learner Participation

Objects are the unique attributes of a museum, yet many museums and science centres apparently

Figure 5. The two modes of operation of the CONNECT system. The system supports both on-site learning and on-line learning giving access to a variety of resources and collections even to communities well beyond the wall of the science museum, who for geographical, social or historical reasons will never entered the hallowed halls.



seek combination of objects and interactivity. Most of the learning issues were similar either mechanical or digital, either on-site or online. In any case, poor examples, of whatever type, do not substantially contribute to a learning potential of interactives. While many researchers and exhibit designers question the compatibility of objects and interactives, some key principles are emerging. Beyond the naive assumption that digital technologies are inevitably interactive, there are strident demands for clear learning objectives, for learner choice and initiative.

After interactivity, the goal of many museums is learner participation. This may involve a simple feedback (often digital voting), digital storage of images and ideas (for subsequent remote retrieval) or even contributing directly to the museum's own exhibits and interpretation. Digital technologies facilitate many kinds of collaboration – between museum and a learner, between different institutions and among a learner. Exciting examples include those between real and virtual learners and of learners creating their own associations within and between collections. In many ways, the opposite of collaboration, digital technologies also facilitate personalisation. Freed from constraints, both physical and interpretative, of the curator and exhibition designer, any learner may appropriately use technologies to provide a dedicated and personal mentor. A new set of relationships is emerging, between objects, learners and digital technology, in which museums are, above all, places of exploration and discovery. In the museum of the future, distinctions between real and virtual, already blurred, will matter even less as both museums and learners better understand the processes of inquiry and of learning itself. The real key to future development is likely to be personalisation: of interpretation to significantly enhance social and intellectual inclusion; of technology to free both museums and learners from many of the current constraints; of learning to finally facilitate an escape from the deficit models so prevalent in educational institutions and release untold potential, as the individual learner is able to use technologies to exercise choice and to take responsibility for his/her own learning.

POTENTIAL IMPACT OF THE EXPLOAR SERVICE ON EXHIBIT DESIGN

Potential changes and improvements that the EXPLOAR service can produce for the science centres that participated to the CONNECT project became obvious in the course of the implementation of the trials. At the current exhibits the posters and labels occupy half of the available exhibit space, and while they certainly provide useful information, they require long stops for reading, take useful space away from other interesting objects which could be displayed in their stead, and are not nearly as compelling and entertaining as a human narrator (a museum guide) or a video documentary about the displayed phenomenon. The tracking data and the observation of the visitors also revealed that people (especially youngsters) do not spend sufficient time to read all of what is described in the posters to absorb the corresponding information. A great deal of the space occupied by the posters and text labels is therefore wasted, as most people don't take advantage of information provided in a textual form. The video stations, in many cases, complete the narration about the described phenomena and physical laws by showing animations, educational and explanatory videos. While the video stations provide compelling narrative segments, they are not always located next to the object or exhibit described, and therefore the visitor needs to spend some time locating the described objects in the surrounding space in order to associate the object to the corresponding narrative segment. The video stations detract attention from the actual objects on display, and are so much the center of attention for the exhibit that the displayed objects seem to be more of a decoration around the video stations than being the actual exhibit.

The potential improvements to the exhibit layout offered by EXPLOAR system are summarized as follows:

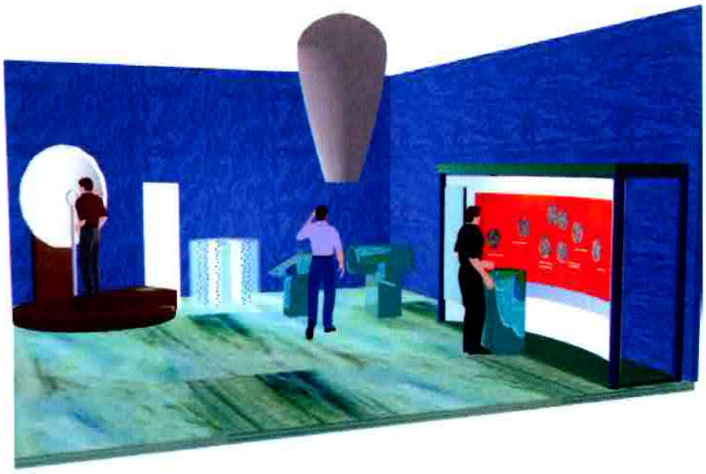
There is no more need to have so many posters and text labels, as the corresponding information is provided in a more appealing audiovisual form, in a video documentary style by the EXPLOAR service. Typically most exhibits have to discard many interesting objects as there is not enough physical space available in the science museum or centre galleries for all objects. The space now made available by eliminating the large posters, can be used to display more exhibits, which are the true protagonists of the museum or the science centre. Figure 6 show how the posters at the exhibition area of EF in Athens can be replaced by more objects and phenomena to be seen and appreciated by the public, taking also into account that the visualizations could be different according to the profile of the visitor.

Visitors are better informed, as the information currently provided by the posters is mostly neglected by the public. The same information would instead become part of the overall narration provided by the EXPLOAR system, and it would be better absorbed and appreciated by the public.

The video kiosks are no longer be necessary because the same material would be presented by the EXPLOAR service. The exhibits would be again the center of attention for visitors, as the wearable's display allows both the real world and the augmented audiovisual information to be seen at the same time as part of the wearer's real surround view. This would again make more space available for additional objects to be displayed.

The fact that the EXPLOAR system presents audiovisual material together with the corresponding object, rather than separately in space and time, and within the same field of view of the visitor, thanks to the private-eye display, is also of great importance.

Figure 6. The EXPLOAR service offers unique opportunities to the exhibit design and development team of the science museums and centres as it gives them the opportunity to personalise the information available to each visitor according to his/her profile and interest and at the same time it eliminates the need for long explanatory texts, pictures and labels by offering visualization of the real physical phenomena.



BENEFITS FOR THE USERS: SCENARIOS OF USE

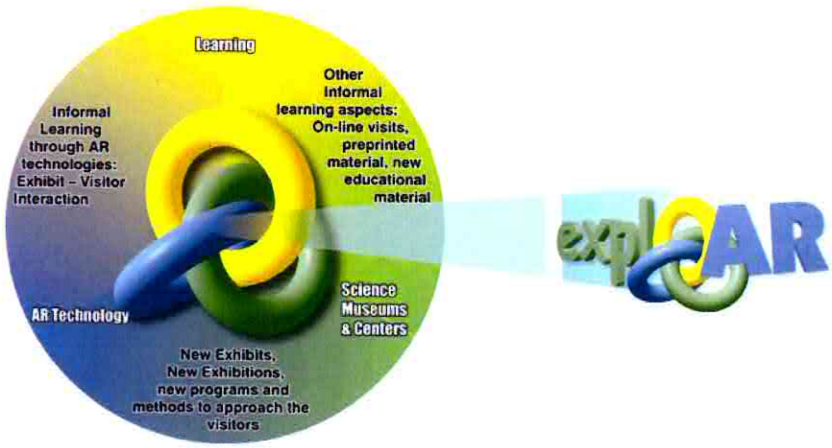
The EXPLOAR service aims to contribute towards this direction by:

- **Engage visitors of science museums and science centres in learning as constructive dialogue** rather than as a passive process of transmission.
- **Facilitate lifelong learning by providing a free-choice learning environment** that permits a plethora of pathways and possibilities.
- **Highlighting key trends in the adoption of digital technologies for learning** within and beyond the walls of museums.
- Providing pointers for potential future developments for curators and developers of digital technologies for museum learning.

Additionally the EXPLOAR service is raising the wider public's interest and awareness on science. As reflected in many surveys realized in the recent years there is a falling interest on behalf of the wider public concerning science, even if individuals in general have a positive perception of science. The main reason behind this attitude is the lack of attractiveness of science matters as well as the lack of relevance to the everyday life. The EXPLOAR service gives to the users a different insight in physical phenomena and physical laws. In this way they are able to observe and thus better understand the world they live, work, play, perform. As a result science is brought closer to the individuals. The way individuals experience science through the EXPLOAR service is expected to have a lasting positive impact on the general public attitude towards science in general. The aim of the EXPLOAR service is to demonstrate an innovative approach that involves visitors in extended episodes of playful learning. The EXPLOAR service offers a "feel and interact" user experience, allowing for learning "anytime, anywhere", open to societal changes and at the same time feeling culturally conscious. These pedagogical concepts and learning practices would address implementing a set of demonstrators (informal learning scenarios), employing advanced and highly interactive visualization technologies and also personalised ubiquitous learning paradigms in order to enhance the effectiveness and quality of the learning process. As the EXPLOAR service is expected to be used from a quite heterogeneous group of people (youngsters, adults, professionals, educators, school groups, families), the scenarios of use have to vary significantly in order to cover the different users needs and their objectives. These scenarios are the basic vehicles for the promotion and the dissemination of the service to the user communities.

Each scenario is accompanied with supportive material for the users in an effort to create a communication channel between the visitor and the museum after the visit. The material includes links to references and additional information from the specific field of interest or relative fields. The content and the proposed activities vary significantly taking into account the needs of the users. The content of the scenarios is presented in an open and modular way allowing for additions and improvements at any time, giving to the user the possibility to get involved according to her/his wish. The EXPLOAR scenarios have been implemented and validated in real conditions initially in two science centres in Greece and in Finland. During the implementation and validation phase of the project the developed scenarios have been also validated in the framework of specific events with the use of the EXPLOAR showcase mobile exhibit in additional science museums and centres (e.g. Deutches Museum, La Cite, CosmoCaixa, Technology Park of Thessaloniki). Some indicative examples are given below that will be tested during the market validation phase.

Figure 7. The EXPLOAR service aims 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 demonstration of a new method of interaction between the visitor and the exhibition. The three main axes of the proposed intervention to the science museum visits and their interrelationship is presented schematically above.



Scenarios for the General Public

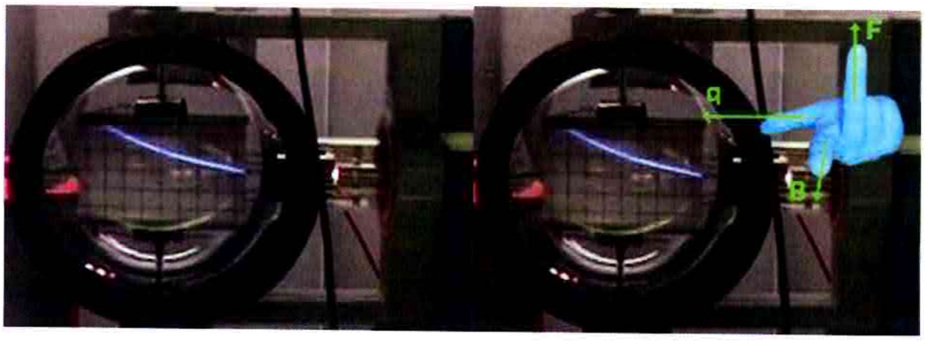
In the science museums and science centres, the exhibits and the related phenomena are embedded in rich real world contexts where visitors can see and directly experience the real world's connections of these phenomena. The add-on of the EXPLOAR visit (compared to a conventional museum tour) is that the visitors with the support of the system will have in their disposal an additional wealth of information. The real exhibits are mixed in their optical view with the 3-D visual objects and representations that the AR system is producing and embedding into this augmented world through their glasses. By this way many "invisible" parameters in physical phenomena (e.g. forces, fields) will be visualised and presented in the eyes of the visitors augmented on the real experiments. For example, a visitor could investigate the question "why do planes fly?" In this case an Aerofoil exhibit could demonstrate the application of physical laws on an airplane wing and their effects on it. To "make the invisible visible," dynamic representations of air movement and the resultant forces can be created. It will also be possible to plot the wing's attack angles vs. lift force. Additionally the airflow could be represented with virtual lines moving towards the wing. These airflow lines could be superimposed on the top and the bottom of the real wing in the exhibit.

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, biology, geology, environmental education, to history and language learning) will be selected and presented in form of multidisciplinary educational scenarios. For example quite complex physical phenomena (e.g. visualization of the E/M waves emitted by the dipole, to observe this experiment will be able to observe the emission of electromagnetic waves by the dipole element, the oscillation of stored energy near the dipole and outgoing waves will be visualized through the augmented reality technique) which usually cause significant difficulties to students will be included. The 3-D visualization of a physical quantity (in this case a force acting on moving charged particles inside a real 3 dimensional magnetic field) which depends on two other independent quantities, is a vital concept in understanding the physical laws and their applications to real life situations. Figure

Figure 8.

Figure 9. (left) Real hands on experiment (right) Augmented Reality version of the same experiment wearing the device. The real exhibits are mixed in their optical view with the 3-D visual objects and representations that the system is producing and embedding into this augmented world through their glasses.



8 at the left shows a real experiment which is accompanied by explanatory text only. In the picture at the right the same experiment is shown to the student wearing the AR system with the addition of a virtual object which in this case is a 3-D hand, serving as "a rule of thumb" showing the geometric and physical connection of the three physical parameters involved (q, B, F). Depending upon orientation of the magnetic field (B) the electron beam is diverted upward or downward. For this change of direction the so-called "Lorentz Force" (F) is responsible. It affects all charged particles, which move in a magnetic field, thus also the negatively charged electrons. The force - and so the diversion - is larger, the stronger the magnetic field is and the faster the particle moves.

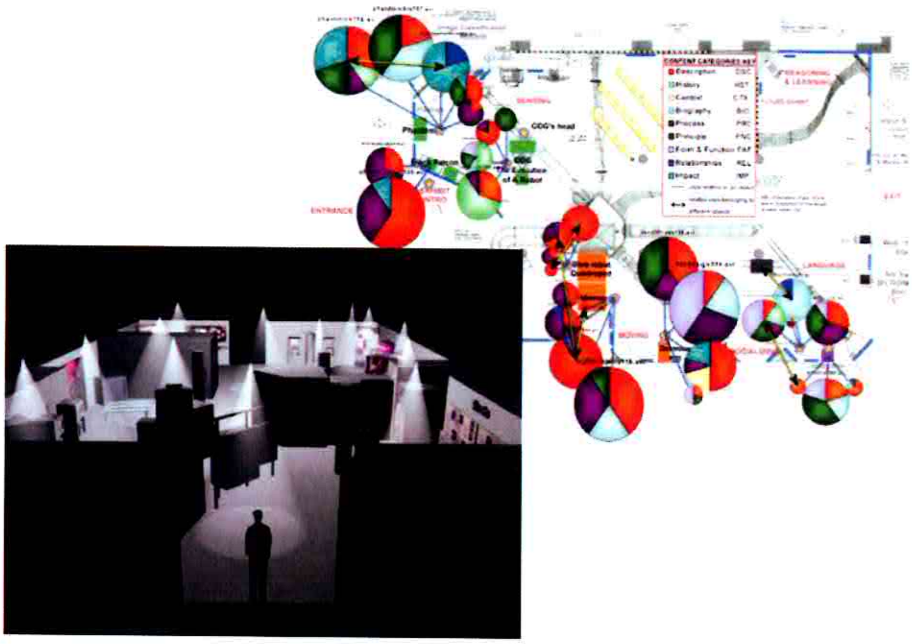
ADAPTING NEW CONTENT ON EXISTING EXHIBITS AND RENEWING THE EXHIBITION

The EXPLOAR service could support the work of the science museum design and development team to innovate the exhibition by adding new content to the optical view of the visitors when this is necessary.

The explanatory and additional materials currently accompany the exhibits are produced for general used and they are presented to all the different visitors categories. By introducing the EXPLOAR service the design team will have the chance to develop different content according to the needs of the visitors (families, school groups, experts, tourists) and in that way to make their visit more interesting and effective. The interaction with the exhibit and the learning objectives would be different since the available information is different. As the exhibit augmentations are easily updated, the information provided by the EXPLOAR service could not only present exhibit relations to everyday life but also current news on topical subjects. With this service curators would be able to present a larger variety and more connected material in an engaging manner within the limited physical space available for the exhibit. Furthermore, inexpensive changes and improvements of the exhibit are greatly supported by the EXPLOAR service. Altering the information provided by the service corresponds to a renewed exhibit with much less resources than a usual renovation.

Finally the museum team would have valuable information to their disposal regarding visitor's preferences and behaviour. Based on the amount

Figure 10. The drawing represents the area of an exhibition hall in a museum and specific data collected during a visit. The conical areas represent the area in which specific information is being available to the visitor for a specific exhibit. The EXPLOAR system is able to track the path of the visitor between the exhibit and to deliver a specific record about the timing and the interactions with the exhibits. In this way a total graph presenting the paths and the interactions with the exhibits for all visitors during a specific period of time can be produced offering excellent data for the evaluation of the design and the approach introduced by each exhibition.



of data downloaded they could calculate the time spent on each exhibit, the trail that they followed, what exhibits provoked visitors to come back, etc. In this way the EXPLOAR service could be used as a supportive tool in the redesign of the exhibition, in the development of new materials and programmes, in the reallocation and the repositioning of specific exhibits.

TOWARDS AN OPEN LEARNING ENVIRONMENT (CLASSROOM AND SCIENCE CENTRE AS WELL) VIA AUGMENTED REALITY (AR)

Computer and communication technologies have profoundly altered our every-day lives. Since more than a decade, great promises for improving education arised, too. However, clear qualitative or quantitative results are still missing. *Making a Science of Education* demands a great deal of high-quality research by focussing on the utilisation and effects of the new technologies in both, school and informal learning environments as well. Only by careful monitoring students' learning outcomes we may narrow the numerous variable spectrum in order to specifically determine the effectiveness of different technologies and new learning methods. (Alberts, B. 2009, 15).

Ilomäki (2008, 33-37) has been mapping a list of teachers' problems when implementing ICT scenarios into educational practices. The author's focus was limited to a teacher's individual characteristic such as individual pedagogical conceptions and problems they experience while preparing the lessons as well. Very often, teachers with coherent ICT skills use more ICT solutions in their teaching and they do it in a more multi-faceted and student-oriented way (Moseley & al. 1999; Hakkarainen 2001; Kankaanranta & Puhakka 2008). Even more, meta-studies related to immersive learning environments seem to provide a clear evidence for a specific efficiency of this type of educational technology: "The more a virtual immersive experience is based on design strategies that combine actional, symbolic, and sensory factors, the greater the participant's suspension of disbelief that she or he is "inside" a digitally enhanced setting" (Dede 2009, 66). The immersive interfaces utilising the visual reasoning ability gives an opportunity to transfer educational experience from classroom to (other) real-world, open learning environments.

COMBINING REAL HANDS-ON LEARNING INTO VISUAL AND AUGMENTED REALITY

Hot Air Balloon is a classical science centre exhibit example provided in several institutes around the world, too. That was one of the reasons why it was chosen as a case within the described CONNECT/EXPLOAR learning scenario. The basic approach was to gain more educational value from the exhibit by using Augmented Reality–technology added to this classical exhibit. The main pedagogical goal was to *teach the skills of doing observations*. This was possible because by the AR-solutions certain invisible phenomenon could be done visible by animations and demonstrations. In this case the main phenomenon was temperature and molecule movement, i.e. Bolzmann constant.

Testing

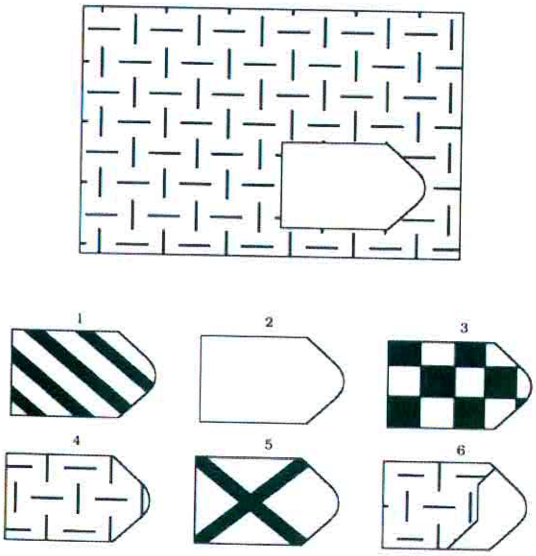
Very often in the field, just paper-and-pencil tests are applied to monitor cognitive knowledge and achievement. However, science and technology has become more and more visual, and many of the skills trained and taught are not textual. Therefore, "there may be a mismatch between the structure of the knowledge and the structure of the print and oral language media traditionally used both impart and test that knowledge (Greenfield 2009, 71)". Consequently, testing in this study contained also non-text based tests.

Tests for the Students

First of all, we applied a visual reasoning ability -test, in detail, the VRA-Visual Reasoning Ability test published by Raven (2000). With regard to the virtual and visual nature of the topic, three major issues supported our choice: 1. the test is standardised, approved and used in many countries and cultures; 2. no translations are needed; and last but not least; 3. young people tend to like to administrate this type of test which they don't perceive as formal education type of task.

Secondly, for measuring the motivation (intrinsic, instrumental, and situation motivation) we administered two measures, the one of Deci & Ryan (1993) called IMI (Intrinsic Motivation Inventory) and the one of Salmi (1993; 2003) on our pre-test schedule. Thirdly, the cognitive knowledge based on 13 items was monitored on two different schedules, before and after the AR-intervention and science centre visit. Forth, we classified our participants with regard to their school grades given by their teachers in science, mathematics, and native language into three categories: A+ = Above average (25%), A = Average (50%); A- = Below average (25%).Finally, we

Figure 11. Raven Test. An example of the standardised test item. Raven 2000; Series 3.



monitored the usability by applying the so called HCI-evaluation method which provides a specific feed-back with regard to the subjective feelings related to the technical usability, psychological usability, and the learning experience.

RESULTS AND DISCUSSION

Usability

A major character of any virtual and especially Augmented Reality technology lies in its' overwhelming effect as visual experience . Especially for a first time, user mostly find the tool effective and exiting, but may also feel frightened or physically unpleasant. A usability evaluation by a questionnaire and interviews (n: 78 students) revealed the following details:

The students experienced the *Combination of Real & Augmented reality* fascinating (mean 5,23; scale 1-7). However, the feed-back could have been even higher. The teenagers did not feel it "very cool".

The *Technical usability* did receive high scores (mean 8,44; scale 1-10). The best score (9,2) was by the item "dryness in eyes" and even the lowest "visual fatigue" was as high as 7,9.

The Psychological usability (mean 6.92; scale 1-10) was not as advantaged as the technical solutions. The lowest score (6.6) was received by the item *frustrating – satisfying*. Meanwhile the best feed-back was given to the item *terrible – wonderful* (7.2).

The overall results indicated that the students liked the experience and their situation motivation was positive to start the testing of the equipment. Especially the technological comfort was at least adequate.

In all the tests above the younger students (aged 11-13 y) gave clearly higher scores about the AR-effect than the older students (aged 14-15 y). The difference was in all aspect – Real & Augmented; Technical; Psychological - statistically significant ($p < .05$). No statistically significant gender differences were found. This is an important result because very often the high-tech or ICT-solutions are classified as male activities.

Knowledge Learning: Pre-test

High achieving students (who where above the average with their school grades, i.e. A+) unsurprisingly performed better in the pre-knowledge test (see the figure below) compared to average and below-average peers. Therefore, strong correlations applied.

The differences between the groups (A- ; Average; A +) were even clearer *inside the test group* as can be seen from the following figure:

The same trend was visible also *in the control group* as shown in the results in the next figure:

Knowledge Learning by AR-technology: Post-Test

Again, high achiever performed clearly best in the post-knowledge test, too (see figure below)

However, low achievers were *clearly catching up with* the others. The difference to their higher achieving peers decreased substantially.

The implementation of Augmented Reality in the context of the Hot Air Balloon exhibit unveiled similar results: While the high achiever again did best in the post-knowledge test, low achiever again were *clearly catching up with* the others. This was especially true for the girls who also managed well in the VRA-Visual Reasoning Ability test. It seems like that *visualising* very theoretical scientific phenomenon of molecule movement) increased the understanding substantially for pupils who otherwise had severe difficulties.

Knowledge Learning: Control Group without AR-Technology

The control group attended the science centre exhibition implementation with the same kind of pre- and post-lesson in the school. However, they studied the Hot Air Balloon content in the exhibition in the traditional way (with the text, label, and guide). The results were quite different from the AR-test group (see next figure) since low achievers were *not catching up with* the others.

The following figure confirms that gap between the low-achievers and the students with the higher school grades remained:

This is an essential result which needs further analysis. It seems evident that the use and application of the Augmented Reality might give certain advantaged for some of the less-than –average school-success students. Especially the girls were

Figure 12. School success vs. Knowledge learning pre-test [scale from 0 to 13]

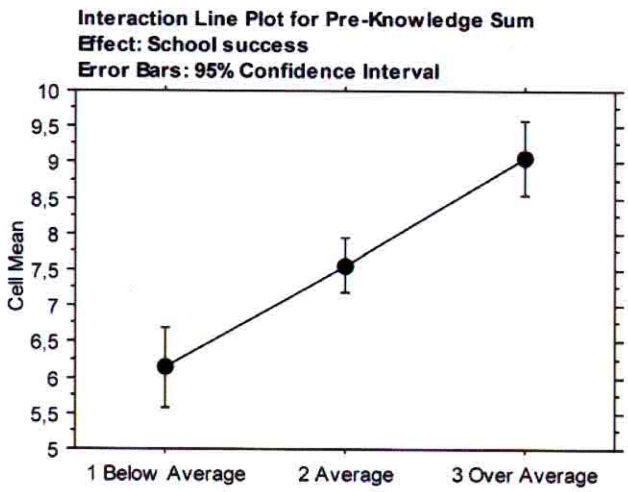


Figure 13.

Unpaired t-test for Pre-Knowledge Sum
Grouping Variable: School success
Hypothesized Difference = 0

	Mean Diff.	DF	t-Value	P-Value
1 Below Average, 2 Average	-1,121	158	-2,945	,0037
1 Below Average, 3 Over Average	-2,845	102	-6,428	<,0001
2 Average, 3 Over Average	-1,724	160	-4,350	<,0001

Figure 14.

Unpaired t-test for Pre-Knowledge Sum
Grouping Variable: School success
Hypothesized Difference = 0

	Mean Diff.	DF	t-Value	P-Value
1 Below Average, 2 Average	-2,172	56	-2,991	,0041
1 Below Average, 3 Over Average	-3,050	41	-3,943	,0003
2 Average, 3 Over Average	-,878	69	-1,681	,0974

Figure 15. ***School success vs. Knowledge learning post-test (after AR-use) [scale from 0 to 13]***

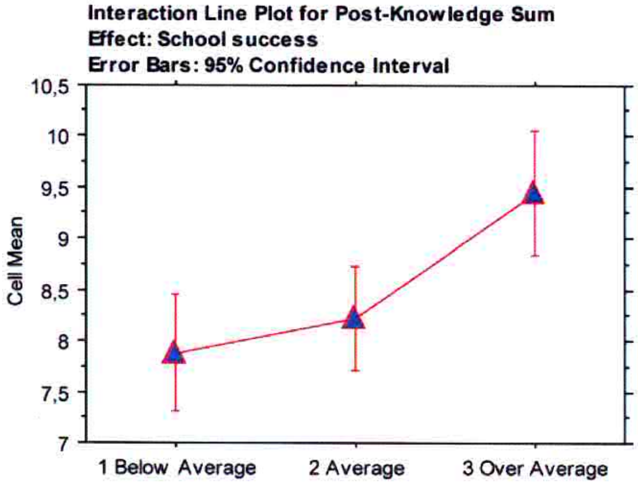
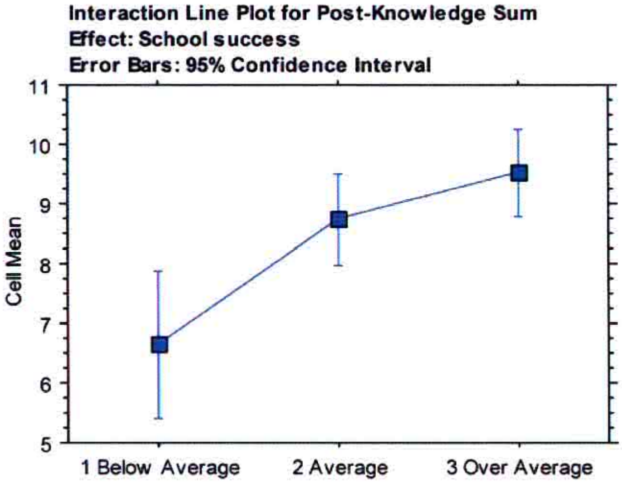


Figure 16.

Unpaired t-test for Post-Knowledge Sum
Grouping Variable: School success
Hypothesized Difference = 0

	Mean Diff.	DF	t-Value	P-Value
1 Below Average, 2 Average	-,345	150	-,823	,4119
1 Below Average, 3 Over Average	-1,567	95	-3,764	,0003
2 Average, 3 Over Average	-1,221	147	-2,826	,0054

Figure 17. School success vs. Knowledge learning post-test (control without AR) [scale from 0 to 13]



receiving better learning results. This is maybe related to the fact that they also managed well in the VRA-Visual Reasoning Ability test. It seems like that *visualising* very theoretical scientific phenomenon like the molecule movement made it much more understandable for students who otherwise had severe difficulties in understanding it.

TEACHER SURVEY AND EVALUATION

The recent *Rocard-report* [*Science education now: A renewed pedagogy for the future of Europe*] (2006) is describing the situation mostly in the pre-schools, primary and secondary schools while we also see the trends around the formal education. The role of informal learning is increasing in the modern societies – meaning the countries which are developing their societies by investing and creating opportunities for research, innovations, and education. The phenomenon is closely related to the growing impact of science and technology in our everyday lives. Lifelong learning needs new practical forms and the formal education can learn something from the informal, open learning environments like the science centres.

The Rocard report specifically underlines the term *Inquiry-Based Science Education*. One of the weaknesses of school's science teaching has been that the studies and lessons at school are mainly deductive. There are some exceptions in some schools, but, historically the main trend in the European science teaching pedagogy has applied "Deductive approach". In this approach, the teacher presents the concepts, their logical – deductive – implications and gives examples of applications. This method is also referred to as 'top-down transmission".

"Hands-on learning" is the main pedagogical principle of the science centres. On opposite to "Deductive", it represents the "Inductive method". This classical "learning by doing" method is something that the science centres have been pioneering in Europe during the last decades. The multidiscipline contents of modern science centre exhibitions form a unique and reliable learning source for inductive, Inquiry-Based Science Education.

Similarly, the Rocard-report (p.7) requests new forms of teacher training, too: "Teachers are the key players in the renewal of science education. Among other methods, being part of the network allows them to improve the quality of their teaching and supports their motivation. – Networks can be used as an effective component of teachers' professional development, and they are complementary to more traditional forms of in-service teacher training and stimulate morale and motivation."

Background

The presentation of the "Hot Air Balloon" is a classical science centre exhibit in several institutes around the world. That was one of the reasons why it was chosen as a CONNECT-case for the research and development. The idea was to gain more educational value from the exhibit by using Augmented Reality –technology added to this classical exhibit.

The main pedagogical goal was to improve skills for individual observation. This was possible because by the AR-solutions certain invisible phenomenon could made visible by animations and demonstrations. In this case, the main phenomenon was the content of temperature and molecule movement. During the very first test of the Augmented Reality –equipment with the Hot Air Balloon seemed to work and give practical results, but at the same time, using the computer aided pre-lecture material (VSTP=Virtual Science Thematic Park) caused several difficulties.

Even teachers with clearly better than average knowledge and skills related to computers, ict, and e-learning had severe difficulties in using the pre- and post-learning solutions. After the pre-testing periods and teachers training workshop it became evident that the computer aided pre-lecture system (VSTP) was all too complicated to use for individual teachers – even for them with a long experience of ICT-pedagogy! The system had typical proto-type difficulties in reliability and usability. Therefore, an intensive training seminar for teachers was offered in order to learn both, the technical use of the system and the application of relevant contents. These experiences, inputs and results were utilised in the final test runs.

TEACHER EVALUATION TOOL: THE ROLE OF ICT IN TEACHING AND LEARNING

As the pedagogical context for the development of AR-system the "NEW EDUCATIONAL MODEL OR PARADIGMS" (Hermant 2003) was used to receive the feed-back from the teachers. (Figure 18. below; original the EU-Minerva programme)

The teachers' (n:182) opinions and visions concerning the AR-technology were monitored by interviews and a tool called "New Educational Models or Paradigms", which is 1) describing the e-learning process by the terms *Role of ICT*, 2) showing the actual *Changes in learning environment*, and 3) defining *Innovative learning activities*.

The educators and teachers as well underlined the main characteristics of the model as following features and ranking order which differ clearly from their opinions about the ICT based education in the classroom setting.

Innovative Learning Approaches: *(i) Integration of other learning environments than the school; (ii) differentiated learning depending on different ways of perception; from teacher-controlled learning to pupil orientated learning; context-related knowledge*Role of ICT:

ICT as connection between learning environments; (ii) ICT as instruction tool; ICT as communication forum; ICT as mediaChanges in Learning Environments:

Technological innovation; (ii) new physical space; (iii) changes in roles and responsibilities of pupils; (iv) changes in roles and responsibilities of teachers

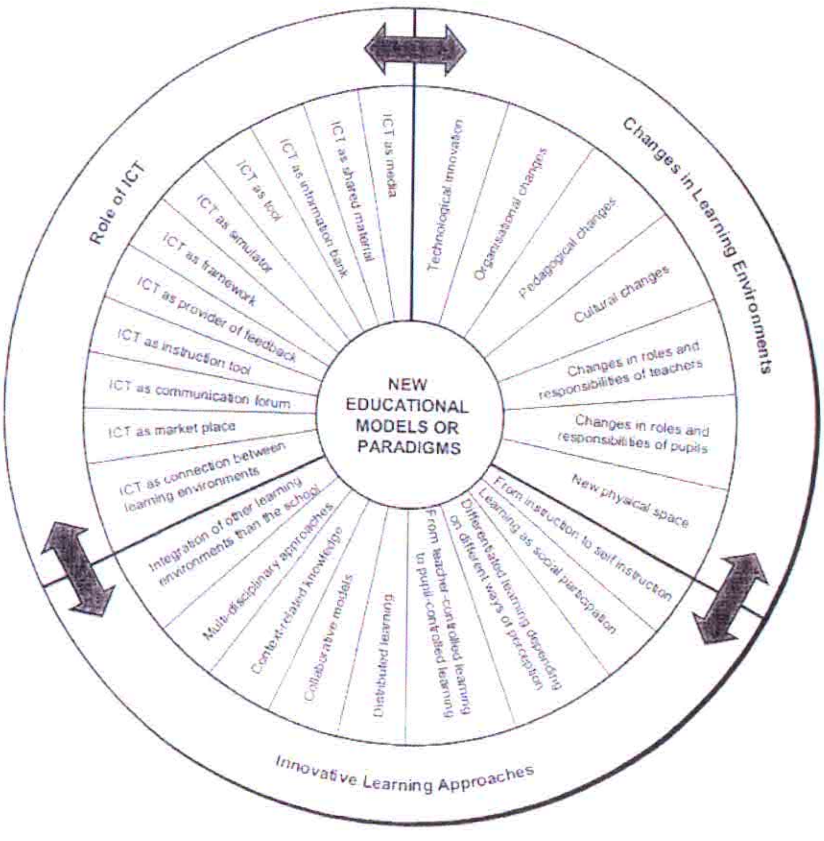
As the result of this inquiry, the pedagogical experts and teachers attending the process underlined as the main characteristics: innovative

Figure 18.

Unpaired t-test for Post-Knowledge Sum
Grouping Variable: School success
Hypothesized Difference = 0

	Mean Diff.	DF	t-Value	P-Value
1 Below Average, 2 Average	-2,095	54	-2,855	,0061
1 Below Average, 3 Over Average	-2,876	39	-4,453	<,0001
2 Average, 3 Over Average	-,780	67	-1,411	,1629

Figure 19.



learning approaches, integration of other learning environments than the school, differentiated learning depending on different ways of perception. The main element was, however, moving from teacher-controlled learning to pupil orientated learning with context-related knowledge. It was also important that the teachers were no impressed about the technology itself but seeing ICT as connection between learning environment, an instruction tool. This can lead in best case– according the teachers' interviews – into changes in roles and responsibilities of pupils –and teachers.

Pre-Visit Stage: Teacher Feedback

The subject matter of the exhibit was part of the teaching of the school for all the teachers, and the timing did not cause any problems – mainly because in the school system of Finland the teachers are pedagogical experts who have the right and obligation to apply the curriculum and its timing during the school year. The teachers were informed about the opportunity to visit the exhibit in August when the school year started so they did not have difficulties scheduling the visit in October-November according their curriculum. – This process reflects also the ordinary visits to the science centre in Finland: the teachers make their plans normally 2-3 months before their visit to ensure the content of the visit to their ordinary school schema.

As the main objectives for the visit to the science centre *motivation* and *learning by doing* were mentioned. Specific content of the one single exhibit (Hot Air Balloon) was not so essential, but mentioned. Also the AR-technology was focus of visit for some teachers.

As supplementing reasons for a visit in a science centre the teachers mentioned a) the other exhibitions content as an entity and b) having an opportunity to utilise varying learning methods.

As a pre-visit activity the groups did use the computer aided (VSTP) lesson which lasted about one to two class periods (mainly more than one because of the technical complexity of starting the computer, connecting to platform, and getting instructions, and help for usability).

The help of the pre-visit –activities: all the teachers replied that the main effect of the VSTP-computer aided pre-lecture was for *the orientation for the visit* itself, and *the focus of the visit* to the Hot Air Balloon single exhibit. Of course the teachers mentioned also the cognitive learning effects, and but they did on see this time as the central objective of the project, but more the learning to learn –process.

Visit Stage: Teacher Feedback

All the teachers and classes had basically the same post ICT-learning activities (CONNECT-EXPLOAR platform) by repeating the main cognitive content of a specific topic. Most classes spent one to two class periods for a selected module. Teachers used a visit as an "integrative science learning" by forming links to other topics (such as Maths, English, and also visual arts lesson). Some teachers integrated the tests (knowledge, motivation, etc.) into their teaching by rating them as a support for their pupils' learning process.

The teachers did not totally agree that learning objectives they had set for the visit were fulfilled. The main reason was that the teachers expected the Hot Air Balloon experiment with the AR-equipment would have been longer than 20-30 minutes, because many other "demonstrations" at science centres last approximately 30-45 minutes. However, the teachers felt that the visit was clearly positive for the learning objectives especially learning to make observations.

The co-operative learning nature of the visit was found important by the teachers - although the very basic nature of the use of the AR-equipment is individual: only one person can use it at the same time. The reasons why the teachers felt that it was encouraging the students for co-operation related to the facts that a) they had prepared the visit together with at the classroom (typically two pupils per computer) and b) the students visited the exhibit in pairs discussing about the topic although only one student could use the equipment.

According the teachers, the students were using the AR-exhibit on their own, freely and by their on conditions. This is very natural because the AR-technique is based on self-centred orientation excluding the outer world or dominance by other people. It captures the user inside the intensive AR-world.

The teachers felt that the visit to the science centre was improving the attitudes of the students both towards the science in general and the specific subject matter.

Post-Visit Stage: Teacher Feedback

All the teachers and classes had basically the same post ICT-learning activities (CONNECT-EXPLOAR platform) by repeating the main cognitive content of a specific topic. Most classes spent one to two class periods for a selected module. Teachers used a visit as an "integrative science learning" by forming links to other topics (such as Maths, English, and also visual arts lesson). Some teachers integrated the tests (knowledge, motivation, etc.) into their teaching by rating them as a support for their pupils' learning process.

Half of the teachers were sceptical as their first experience about the cognitive learning results. However, there where not negative, but more curious to hear the research results. The other half of the teachers were convinced that the main principle of the phenomenon became clear for the pupils during the process.

For the subject matter, the most important element according the teachers was "learning by doing" and the opportunity to apply a method "to make observations". However, the teachers also replied that the AR-exhibit was only one part (lasting 10-15 min) of the whole science centre visit (lasting 3 hours 30 min) with many motivating elements. The teachers appreciated the entity: Pre-lecture + Visit + Post-lecture, because it gave back added-value for their work (while the teachers had invested a lot of their – especially mental – resources for the process).

All participating teachers felt that the new AR-technology provides better opportunities for learning and teaching. The limitations of the stage of the technology were clearly seen and recognised by the teachers. The technology was still on demonstration or proto-type level. Some teachers were comparing it to the period when the first pc-computers came to schools: ms-dos versions where demanding specific and often purely technical skills from the teacher who could not concentrate into the pedagogy and content topic. This was exactly the case of the AR-technology now, but it was fruitful to use. As the strongest side of the AR-solution the visualisation was named most often.

CONCLUSION

Open learning environments provide an holistic and integrated learning environment. There is an intention and a need as well to provide opportunities to lifelong learning and individual study: A learning environment is a place or a community where people can draw upon resources to make sense out of things and construct meaningful solutions to problems.

The main principles of planning open learning environment are based on learner's active learning and interaction. Learning is seen as an active process in network environment through information and communication technologies. Information technology can be an active part of the open learning environment or just a device to help in occasional learning situations. By using the modern technology possibilities arise to emphasis flexibility and mobility in study situations.

According the written and oral monitoring with the teachers and educators, the structural factors of an open learning environment related to combination of Augmented Reality, classroom, and hands-on exhibit can be categorised into four groups (see Sariola 1998; Salmi 2005; Ilola 2008; Maydas et. al 2009; Dede 2009): **(i)** Physical openness points out the accessible of facilities to be used for flexible teaching and learning situations. (ii) Didactic openness concentrates on the construction of a group experience. The learners should have enough opportunities for decision-making in their studies from the teacher, otherwise psychological and virtual aspects cannot be actualised. (iii) Psychological openness consists of a feeling of independence of space and time. This individual feeling, that a learner can influence own learning success substantially promotes motivation for learning. (iv) Virtual openness is made by using information and communication technology in teaching and learning process.

Open learning environments useable at school (and at home for informal learning!) need independence from platforms. They need scalability, multi-user capability, based on an open standard, in order to support a hypermedia structure which allows a working with free or inexpensive software, use client/server architecture, support communication via a network, integrate other interactive media and support working with real time applications. In summary, to support self-organised a learning within a computer mediated learning environment, three principles need discussion. Students specifically need to **(1)** create their own documents and construct links between documents **(2)** communicate with each other to **(3)** cooperate and collaborate on their work/learning. In order to create a appropriate combination of school classroom, exhibition and the web, science centres need to meet the challenge. This has been pointed out earlier in literature (Jones 2005; Salmi 2005; Piazzalunga & Barretto 2005; Ilola 2008), and it was also the main message of the feed-back of the teachers attending the CONNECT-EXPLOAR–Augmented Reality project. However, ICT based education needs content. To create learning objects with the structure of a pre-lecture – visit – post-lecture design with the specific help of ICT-methods, the combination of VSTP (Virtual Thematic Science Park) and AR-Augmented Reality approach at an exhibition will support a work in-between the classroom and exhibition also during the visit. The open learning environment consists typically of a combination of real physical environments and Augmented Reality ICT-based learning. This type of activities do need further research as new source of learning bridging the gap between formal education and informal learning. Latest signals show that AR-technology is moving from the high-tech and military solutions into everyday educational use with valid content.

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