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VISUALIZATIONS, ANIMATIONS AND SIMULATIONS FOR COMPUTER ENGINEERING EDUCATION: IS HIGH TECH CONTENT ALWAYS NECESSARY?

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Multimedia learning and all its facets (e.g., E-Learning, M-Learning, X-Learning) offers promising tools for Life Long Learning (LLL) and Continuing Engineering Education (CEE). Modern information technology is both, increasing in sophistication and, simultaneously, making it easier to build Learning Objects (LO) containing "high-tech" visualizations, animations and simulations for educational purposes. However, before starting development, it is always necessary to first ascertain, whether "high-tech" content has the potential to enhance the learning processes of the targeted end-users, and to what extent it has the potential. Today, we are facing a large body of empirical studies reporting contradictory results concerning the superiority of "high-tech" Learning Objects in relation to rather "Spartan" textbook lessons. Pedagogical and psychological theories report both pros and cons regarding the efficacy of such objects. Especially within the scope of both LLL and CEE the learning speed is of special importance because learning increasingly is an integral part of today's work process. Based on a series of experiments, in this paper we raise the question whether appropriate multimedia Learning Objects (i.e. animations) enable learners to learn more in less or equal time in comparison to "Spartan" Learning Objects (i.e. purely text-based instructions). Moreover, we exemplify the importance of Human-Computer Interaction (HCI) in instructional design. The empirical results of our study indicated that animations can facilitate the learning process in the domain of engineering education.

Introduction

Visualizations, Animations and Simulations are often assumed to be the best way to learn (Park and Gittelman, 1992); (Davies, 2002); however psychological research has not yet found strong evidence to confirm the superiority of animated graphics (Mayer et al., 2005). However, it is interesting that most of the research carried out was on standard animations (e.g. "on how lightning works" or the typical "how a toilet tank works") and most of the experiments took place in a laboratory setting (Mayer, 2005).

We are of the opinion that research must be carried out in real-life settings and that both the psychological and development aspects are crucial (Holzinger and Ebner, 2003) at the intersection of Computer Science and Psychology. It is increasingly necessary to combine Human-Computer Interaction (HCI), which delivers the necessary theoretical background, and Usability Engineering (UE), which ensures the appropriate practical application of the results (Holzinger, 2005).

In this paper, we raise questions which are based on various experiments, including which factors contribute to the success or failure of multimedia Learning Objects containing visualizations, animations and simulations. In view of life long learning and continuing engineering education an interesting factor is the time a learner needs to acquire certain knowledge; this factor, however, was investigated by only few empirical studies to date.

Theory and Background

Many so-called successful applications of animations turn out to be a consequence of a superior visualization for the animated than the static case, or of superior study procedures such as interactivity or prediction that are known to improve learning independent of graphics (Lowe, 1999), (Betrancourt and Tversky, 2000), (Tversky et al., 2002), (Hegarty et al., 2003).

The most prominent theoretical framework for the explanation of all these findings is the so-called *static-media hypothesis* (Mayer et al., 2005). This theory is based on the *cognitive theory of multimedia learning* (Mayer, 2001) and the *cognitive load theory* (Sweller, 1988), (Tuovinen and Sweller, 1999), (Valcke, 2002). These theories are especially interesting for aspects of CEE and LLL (Sweller, 1989), (Sweller et al., 1990). Basically, this theoretical framework states that a learner's attention span is limited; however, during the learning process, their attention can be directed either to intrinsic, germane, or extraneous processing. *Intrinsic processing* describes a learner's focus on the Learning Object and its key features. *Germane processing* describes a deeper processing of the Learning Objects by its organization to cognitive representations and its integration with existing representations. *Extraneous processing* describes cognitive demands during learning, which do not foster the actual objectives of the Learning Object. Consequently, static media (for example text or images) demand less extraneous processing due to the fact that learners are only provided with relevant information (for example: key images of a physical process), whilst animations require the perception and the integration of a complete timeline of images. Moreover – in contrast to animations – static media allow learners to manage intrinsic processing by controlling the pace and order of the presentation.

The broad basis of empirical research does not allow the preference of either static or dynamic media. Consequently, the question arose, which factors contribute to the superiority of either static or dynamic media. We hypothesize that two factors contribute to the efficacy of learning, i.e. the time provided for learning and the difficulty of the Learning Objects, which were not explicitly investigated. We assume that the more difficult a Learning Object is, the more efficient the use of appropriate animations is.

For the current study, we conducted a series of experiments, which kept the learning time at a low level whilst the difficulty of Learning Objects and test questions were varied.

Method and Materials

Participants

The participants included 49 students of computer science at Graz University of Applied Sciences where the first author held guest lectures in computer engineering education in the winter term 2002/03. In total, there were 6 female and 43 male students (unfortunately, in the engineering domain females are under-represented). The mean age was 20.19 years (SD = 1.50), ranging from 18 to 25 years.

Experimental Setting

A Pre-test-Post-test Experimental-Control group setting in a *real-life* classroom scenario was performed in order to investigate the efficacy of animations for learning in comparison to Spartan textbook lessons. At first, the whole class was informed as to the aim of the study and participated in a pre-test in order to determine their prior knowledge base. On completion, the lecturer randomly selected an experimental group (EG) of 24 students who moved into the computer laboratory, which was next door to the lecture hall.

Meanwhile, a tutor observed the remaining students which formed the control group (CG). Separating the groups took less than 4 minutes. After all of the students were ready, the CG were given copies of a textbook passage (in German language, see figure 1) of the textbook written by the lecturer (Holzinger, 2002); the students were instructed that they were not allowed to look at the material until after a specific signal. The corresponding animations (see figure 1), developed as treatment material for the EG, had been installed at all 24 available computers before the experiment started, in order to begin simultaneously and without any delays or disorientation. As soon as all of the students in both groups were ready, the lecturer gave a signal by knocking on the wall, which was the start for both groups: One group performed a learning session using the traditional textbook lesson to learn a clear-cut topic from communication technology (see section Materials). The other group used interactive animations prepared to learn the same content. The students were allowed exactly 8 minutes to complete their tasks. The 8 minute period was selected during an earlier pilot run in order to determine an average information processing time.

Materials

For the experiment two separate types of learning materials were prepared. Textbook lessons (Figure 1, left panel) taken from (Holzinger, 2002) and corresponding Flash animations (Figure 1, right panel) presenting the same content.

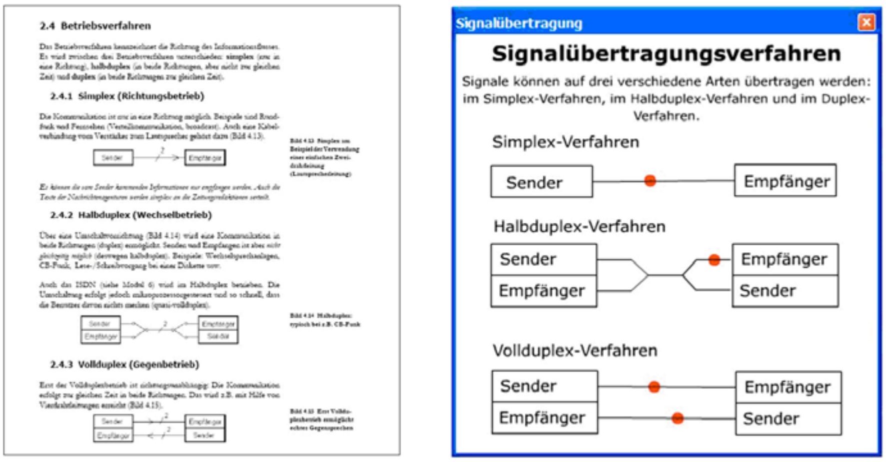

Figure 1. The left panel illustrates the textbook lessons provided in the current experiment – the right panel illustrates the provided animations.

To develop animations, which are as comparable as possible to the textbook lessons, required careful adaptation of the textbook lessons in terms of imparted knowledge and terminology. The amount of learning material was chosen in order to enable a (fictitious) keen learner to gather the entire contents within a single, short learning session. This means, that it was possible for the participants of the textbook group to read through the entire text passages within the 8 minutes. Hence, for the current learning material, we anticipated the same learning time for both experimental groups. To record previous knowledge and the subsequent learning progress in the domain of computer engineering basics, we prepared a paper questionnaire.

With this questionnaire, personal data (for example age and gender) were recorded, a subjective rating regarding the participants' knowledge in the domain of communication technology, and 3 ratings regarding learning preferences (i.e. "I like learning from textbooks", "I like learning from computer animations", and "I am rather a visual learner type"). All ratings were calculated using a scale with six categories, ranging from "I absolutely agree" to "I absolutely disagree". To record the actual knowledge, we used three multiple choice questions which covered the learning material.

For each question, four alternatives were presented, whereby none or all four answers could be correct. The three questions were chosen in order to represent three different levels of difficulty, high (Q1), medium (Q2), and low (Q3).

Procedure

After a short briefing regarding the experiment and its aims, participants received a questionnaire to record personal data, to determine learning preferences, and the participants' prior knowledge in the domain of basic computer engineering. The participants had sufficient time (approximately 10 Minutes) to fill in the questionnaire. After this procedure the participants were randomly assigned to one of the experimental groups ("Spartan" versus "High-Tech"). Then the participants of both groups were given 8 minutes in which to learn. The animations were run on standard Windows PCs with installed Flash. Directly after the learning session, the students completed the second questionnaire without interruption.

Results

We computed the scores of the three multiple choice questions considering the four alternatives of each question. For each question, none or all four answers could be correct. If an incorrect alternative was checked the score was decremented by 1. If a correct answer was checked the score was incremented by 1. Hence, for each question the maximum value was 4. The mean total score across the three questions after the learning session was 9.92 (SD = 0.75) for the textbook group and 11.00 (SD = 0.52) for the animation group. This finding supports a variety of research that reported that improvement due to multimedia is still lower than the expectations (for example (Mayer, 2003)). However, if we distinguish the 3 different levels of difficulty, which were represented in this experiment, we find different results. As shown in Figure 2, the most difficult question Q1 resulted in lowest total score, the least difficult question Q3 resulted in the highest total score. Second, and more important, the higher the level of difficulty the more learning performance was achieved with animations in contrast to textbook lessons.

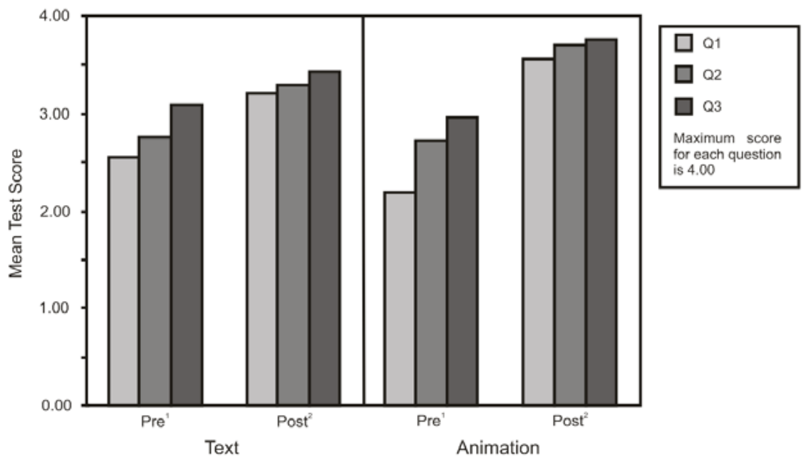

Figure 2. Mean test scores for the multiple choice questions of the current study. Q1 was the most difficult question, Q3 the least difficult one.

As shown in Table 1, for the highest level of difficulty (Q1), we found an increase in the mean test score of 0.67 for the textbook lesson and 1.36 for the animations; this is a difference of 0.69. For the medium level of difficulty (Q2) we found an increase in the mean test score of 0.54 for the textbook lesson and 0.99 for the animations; this is a difference of 0.45. Finally, for the lowest level of difficulty (Q3) we found an increase in the mean test score of 0.33 for the textbook lesson and 0.80 for the animations; this is a difference of 0.47. These results suggest that learners profit more from animations when the difficulty of contents is high.

This is at least true for learning within a restricted time span, as proved in the current experiment. An analysis of variance (ANOVA) reported that the differences in the increase of the total test score from the pre-test to the post-test between textbook lessons and animations were significant on the 5% level in all cases (Table 1).

An interesting finding is that the participants' initial subjective ratings regarding their knowledge in communication technology are not correlated with their test scores (r = -.10).

The reason for this finding might simply be a tendency towards medium ratings; the median for the ratings of this question was 3 in both groups. Also, no correlations were found between the participants' learning preferences and the test scores. Again the reason might be a tendency towards medium ratings. For the question "I like learning from textbooks", the median was 3 for the textbook group as well as the animation group; for both other questions ("I like learning from computer animations" and "I am rather a visual learner type"), the median was 2 in both groups. Still, an interesting finding is that despite this medium rating tendency, learning from textbooks seems to be less popular than learning with animations.

Table 1. *Mean test score differences.*

Difficulty	**Textbook**[1]	**Animations**[1]	**Difference**[2]	**Oneway ANOVA**
Q1	0.67	1.36	0.69	$F(1, 96) = 4.13; p = 0.045$
Q2	0.54	0.99	0.45	$F(1, 96) = 14.82; p < 0.001$
Q3	0.33	0.80	0.47	$F(1, 96) = 8.25; p = 0.005$

[1] Knowledge increase (mean difference between test scores in pre- and post-test).
[2] Mean differences in the knowledge increase between the textbook and the animation group.

Discussion

The current study is a small part of a series of work aiming at finding another brick in the wall of understanding Human Learning supported by new technologies. A large body of studies reported that learning with multimedia Learning Objects (especially animations) does not improve learning success to the anticipated extent, or least contradictory results were found not favoring either static media or animations (Betrancourt & Tversky, 2000; Hegarty, et al., 2003; Lowe, 1999; Tversky, et al., 2002). Few studies, however, explicitly addressed the difficulty of learning material and the time provided for learning.

In terms of both CEE and LLL, these factors, however, might play a crucial role. For example, when learning occurs on-the-job, the learners are often experienced professionals in a certain domain, and learning objects are likely to be very difficult. Moreover, the time factor (and therefore the cost factor) must be considered. If new technologies make it possible to learn the same amount or maybe more within the same period of time, the cost of developing appropriate multimedia learning objects are amortized. The results of the current study suggest that animations can improve learning in situations with restricted learning time and a high level of difficulty. Hence these findings support and extend Mayer's cognitive theory of multimedia learning (Mayer et al., 2005).

Conclusion

The results suggest that computer engineering students profit more from animations when the content difficulty is high. This is at least true when the time span provided for learning is restricted, as in the current experiment.

The implication for CEE and LLL is that animations can enhance learning but only in an appropriate didactic setting. This setting must enable both problem-based learning and meaningful learning with the aim of transferring the acquired knowledge into new practical problems. However, it is absolutely necessary to coordinate educators, psychologists and computer scientists for a close working together in future research and development.

Curriculum Vitae

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PERVASIVE E-EDUCATION SUPPORTS LIFE LONG LEARNING: SOME EXAMPLES OF X-MEDIA LEARNING OBJECTS (XLO)

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In our e-Society the concept of Life Long Learning (LLL) is not merely a buzz word but a necessity. Pervasive e-Education is a challenging way to assist both Life Long Learning and Continuing Engineering Education (CEE). However, research in these areas must bridge the gap between Psychology and Computer Science. Furthermore, research and development must be carried out together. Whichever perspective you take into account, pervasive e-Education requires a complete independence of location – which is more than just being mobile. Text, image, audio, video via Desktop, Television, Pocket-PC, iPod, Mobile Phone – each and every medium and terminal has individual advantages and disadvantages. However, this purely technological perspective is not yet enough. Every Learning Object (LO) must be adjusted to the needs and requirements of the learners and, most of all, it must correspond to a model of psychological learning and motivation including cognitive style, learning strategy and preliminary knowledge. In this paper, we concentrate on our first experiences with X-Media Learning Objects (XLOs) and on how the standard Learning Management System Moodle delivers the X-Media content and which psychological concepts we consider suitable for the use with XLOs.

Introduction

Within our e-Society, it is clear that knowledge acquired at schools and universities – whilst being a necessary basis – may be insufficient for the whole life span. Working and learning are parallel processes, consequently, Life-Long Learning (LLL) cannot be considered a mere buzz-word. LLL is an undisputed necessity within our society (eEurope, 2005). Today, we are facing a tremendous increase in educational technologies and although the influence of these new technologies is enormous, we must never forget that learning is both a basic cognitive and social process (Holzinger, 2000a). Education cannot be replaced through technology (Salomon, 1984), (Kozma, 1993), (Clark, 1994). However, the complete independence of both location and time is often emphasized as *the* main advantage of e-Learning (Collis, 1997), (Maurer, 1998), (Holzinger, 2000b). Nevertheless, traditional e-Learning is generally designed for desktop computers. Even the use of notebooks cannot completely fulfill the aim of learning "wherever and whenever a learner wants to". Mobile learning (M-Learning), based on mobile devices (Sharples, 2000), (Tatar et al., 2003), (Holzinger et al., 2005a), can address the above mentioned criteria. One advantage is the high availability of such devices, e.g. mobile phones. According to the 5th Telekom report of the European Commission, the market penetration of mobile phones in Austria is currently at a level of 99% (although not all of these are suitable for M-Learning). It can be emphasized that the majority of the population have a mobile at hand most of the time. The application of such technologies in conjunction with appropriate Learning Objects (Holzinger et al., 2005b), enable constructivist learning approaches (Papert and Harel, 1991). Such approaches include for example

Situational Learning (Schank, 1993) or *Just-in-Time Learning (JIT) or Learning on Demand (LoD)* combined with *person-centered approaches* (Motschnig-Pitrik and Holzinger, 2002). Successful LLL requires both technological and psychological concepts to enable learners of all age groups to access Learning Objects, which are adapted to their needs, knowledge, abilities, and the learning contexts and environments (Holzinger and Nischelwitzer, 2005), (Holzinger et al., 2005a), (Holzinger and Motschnik-Pitrik, 2005).

From traditional e-Learning to pervasive e-Education

The landscape of modern e-Learning is dominated by Learning Management Systems (LMS) whether open systems such as Moodle (Chavan and Pavri, 2004) or commercial systems such as WebCT (Garrett, 2004). These are widely used amongst universities and continuing education institutions. Successful pervasive e-Education must include solutions for the interoperation with these systems in order to bring available content to *every end-device* and to assist with the aim of maximum benefit for the learners. In this paper, we expand M-Learning to X-Learning and present working examples of X-Media Learning Objects (XLO) for five target media, i.e.: Personal Computers; Television; PDA's; Audio devices (MP3 players), and Java-enabled mobile phones.

The iXmedia Learning Engine

The vision of the iXmedia Project (**www.ixmedia.biz**) was the creation platform for almost every type of learning technology and learning methods in order to address various types of learners (e.g. audio; visual; night; day; situational etc.). The central administration and content management was done with Moodle.

For each medium the focus of the presentation must be carefully chosen:

- WWW: text, pictures, movies, MP3 files;
- MEDIA CENTER: pictures, movies, MP3 files, little text;
- PDA: text, pictures;
- MP3: MP3 audio files;
- MOBILE: text, pictures; animations

For the experiments the following Hardware was used:

- WWW: Standard Desktop-PC (with internet access), resolution ranging from 768 × 1024 px to 1200 × 1600 px
- Microsoft® MEDIA CENTER and a standard television set, resolution 640 × 480 px
- PDA: Pocket PC with Windows Mobile (with WLAN and USB connection to the PC), resolution 320 × 240 px
- MP3: Apple iPod Audiodevice
- MOBILE: Mobile Phone (with GPRS and Java capability), resolution from 160 × 132 px to 176 × 208 px, minimum display size: 150 × 130 px; In order to use audio and video: MIDP 2.0 or MMAPI 1.0, or a higher version of this Java APIs;

Besides a functioning Moodle Server for the experiments the following Software was necessary:

- MCL File for the Windows Media Center (in order to directly open the learning engine);
- AvantGo-Client for the PDA;
- Microsoft Active Synch (in order to synchronize PDA with PC)
- Podcast for MP3-Players
- Remote Display Control for the PDA (in order to access the PDA via PC or notebook and work on it by using the display and keyboard).
- Mobile Learning Engine (MLE, www.elibera.com) for the mobile phone (in order to connect to the server to download contents)

Technologically, PHP was used as basic technology for all media. PHP is a script language, which is mainly used in the development of dynamic web applications. One advantage of PHP is that the client does not need to download PHP as for example with JavaScript. The source code is generated directly on the server and pure HTML files are forwarded to the client. The content of the iXmedia Engine is stored in a MySQL database on a central server. The different devices are connected to this database and the content is downloaded and presented on each end-device. Due to the central storage of the data in a well-designed database confirming to the normal forms, redundant data can be avoided and the content can be updated quickly.

The MP3 player is the only exception: It does not connect directly to this database. A PHP script provides the content loading feature via pod cast directly to iTunes and afterwards to the MP3 player. Pod casting is the distribution of audio or video files, such as radio programs or music videos, over the Web using either RSS or Atom Syndication for listening on mobile devices.

The Creation of X-Media Learning Objects

The central administration is done with Moodle (http://dmt.fh-joanneum.at/upm/xlearning/Moodle). The teacher creates a WWW course by creating a new category. This is the main course (standard Moodle Web course) and can be specified using any name. Within this course, four sub-courses can be created, each corresponding to one of the four supported media types and which must therefore be named: TV, PDA, MP3 or MOBILE. These are hidden, only the main course is visible to the end-user and can contain any files.

- In the WWW course, teachers can create HTML or text sites and can upload all the data they want to or they can link this content to other websites.
- In the TV sub-course directory, teachers can create HTML or text sites or they can upload pictures, videos or Flash files. These data can be optimally displayed on the Media Center.
- To achieve a learning success on the PDA, teachers can create HTML or text sites.
- MP3 files are created through Text-To-Speech conversion but it is also possible to use any self-recorded audio files.

To enable access of content via a mobile phone, teachers can create Learning Objects directly in Moodle within the MOBILE sub-course directory, where the MLE-Editor is automatically launched (see figure 1). This is a WSIWYG-Editor, where the dimension of the created Learning Objects on the target device can be adjusted. After completion this content is automatically converted into XML-format, which can be displayed on a mobile phone.

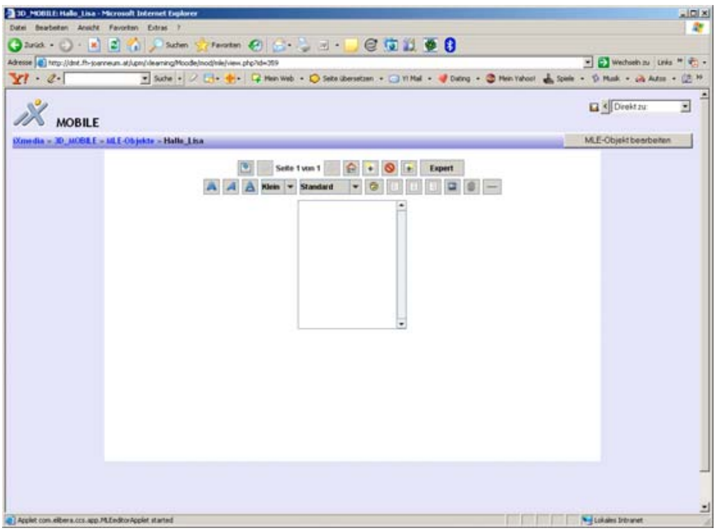

Figure 1: The content creator shows how the content will look within the target environment

The use of the iX-Media Learning Engine: Technological Aspects

After registration in Moodle, the end-users receive all relevant access information and are able to choose between different courses. After downloading the software required for different end-devices the end-users are able to use the content on the selected end-devices. It is also possible to inform users about news via E-mail or RSS-Feeds. Of course, the use of other standard modules, which are included in Moodle, including chat, forum, glossary, tests, Wiki and workshops, is possible. The application is also compliant with SCORM (Holzinger, 2002).

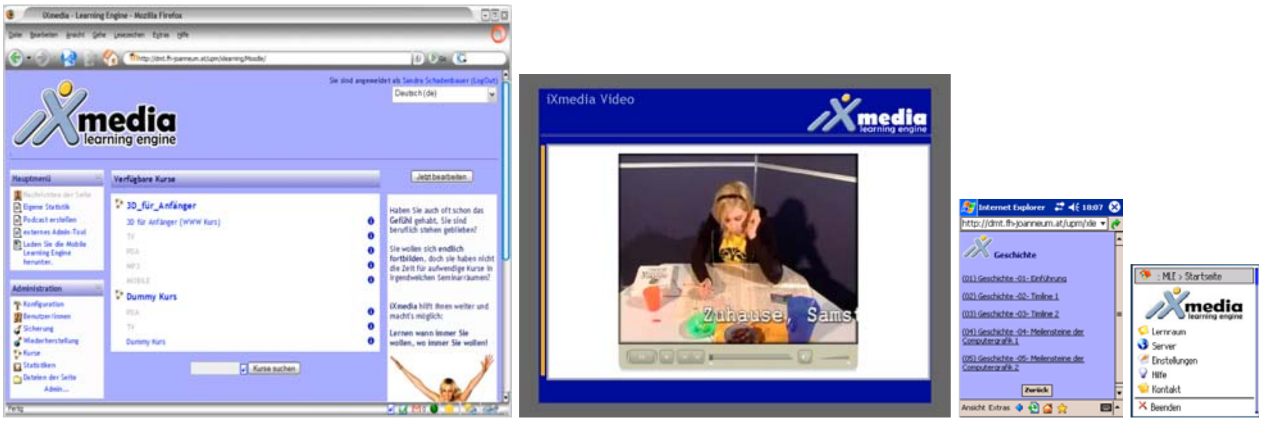

Figure 2: From left to right: Examples on Moodle, TV, PDA and Mobile phone

The use of the iX-Media Engine: Psychological Aspects

The ability to access XLOs with a variety of different end-devices in different situations, contexts and environments is a major challenge for both Computer Science and Psychology.

Situated Learning, which can be seen as a combination of both cognitivistic and constructivistic approaches (Brown et al., 1989), (Billett, 1996) permits the acquisition of knowledge in an *everyday situation;* this means that learning can be seen as a *socio-cultural phenomenon* (Kirshner and Whitson, 1997). Situated Learning places the learner in the center of an instructional process consisting of content, environment, community and participation. This supports the argument that learning is both a cognitive and social process (Holzinger, 2000a).

This is similar to the idea of *Collaborative Learning,* which refers to an instructional method in which students at various performance levels work together in small groups towards a common goal. The students are responsible for one another's learning as well as their own and the success of one student helps other students to be successful. Evidence for positive effects of such approaches were found early by Vygotsky, who discovered that students are capable of performing at higher intellectual levels when asked to work in collaborative situations (Vygotsky, 1978). Meanwhile, many researchers proved that such methods improve problem solving strategies and even if collaborative learning does not necessarily lead to better factual learning, there is a large body of evidence that the environment in which the learning material is presented (independent of social interactions) significantly affects the recall of learned information.

In an old but extraordinarily interesting experiment, (Godden and Baddeley, 1975) compared the learning performance of scuba divers 20 feet under water and onshore. The results of this experiment showed that the recall rate of learned material was significantly higher when the recall was required in the same context (under water versus onshore) as in the context the material was learned. Similar effects were found for emotional and physical states (Teasdale and Russel, 1983). Moreover, there is some evidence that the depth of interaction with learning material significantly affects the learning performance and also the preferences towards certain learning modalities.

For example (Mannes, 1988) found, that students who were required to memorize content, preferred text objects, whilst students required *to solve problems* preferred graphical objects; additionally, problem-solving settings depended more on prior knowledge than memorizing settings. Applying all those theories to LLL, X-Media Learning Objects used in a multitude of contexts and accessed with a multitude of devices enables collaborative learning. In our experiments, learners got certain XLOs via mobile phones just-in-time; parallel they were able to start collaboration and discussions. This possibility is definitely not provided to such an extent by traditional E-Learning solutions.

Conclusion

Our first experiences with X-Media Learning Objects (XLOs) showed that these have enormous potential for future pervasive e-Education and are thus ideally suited for LLL and CEE. However, since the first step is always technological developement, the inclusion of psychological considerations as early as possible is a necessity in order to adequately develop user-centered technology, consequently applying Usability Engineering Methods (Holzinger, 2005). Our first experiences with XLOs suggest that *situation learning* and *collaborative learning* by means of these can be a valuable contribution to e-Education. It is essential, that by combination of real-life problems, parallel to adequate information, thinking processes of learners are activated. Hence, we are optimistic that X-Media will be a substantial part of future (continuing) education. Future research must address questions as to both acceptance and learning success with XLOs accessed with different end-devices.

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