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Collaborative Remote Laboratories in Engineering Education: Challenges and Visions

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Abstract:

Remote Laboratories appear to be natural tools for teaching collaborative work skills, because they offer interesting perspectives for social and collaborative learning from multiple and distributed locations. However, remote labs separate users from the real workbench and their traditional tools. Accordingly teleoperating remote lab equipment requires a sufficient degree of interactivity and vividness to give the learner the impression of actually being in the lab. Effective use of collaborative remote labs is based on a feeling of shared space, time and reality, determined by technological and human factors. We will review related concepts and discuss lessons learned from own research and prototype development. New developments involve the use of Mixed Reality techniques and open perspectives for future research.

Introduction

Remote laboratories have been an important topic of research during recent years, and it is not difficult to find publications that address this area[1]. The developments in Internet technology, notably the World Wide Web and its associated technologies (hypertext, web browsers, etc.) provided the basis for the evolution in remote experimentation from the beginning of the 90's, although the basic ideas are much older. Remotely operated apparatuses have long been desired for use in dangerous or inaccessible environments such as radiation sites, marine and space exploration. For example Goertz and Thompson (1952) developed the first telemanipulator in 1945 for the remote safe handling of radioactive isotopes. See Sheridan (1992) for an excellent review of the extensive literature on teleoperating remote systems.

Although remote laboratories have proven valuable for a more efficient exploitation of laboratory resources and can be shared among participants from different places, there has been less research on collaborative applications. We believe that remote laboratories are ideal tools for teaching distributed collaborative work skills, because they offer perspectives of shaping teaching

[1] For a literature survey see Ma & Nickerson (2006).

scenarios which are close to real distributed engineering team work. Likewise, remote labs can be shared by many institutions and students worldwide. This may promote the interaction of faculty and students across laboratory-based and technology-oriented subjects in different countries.

It is widely believed that collaborative experiences are powerful drivers of cognitive processes and can significantly enhance learning efficiency. The benefits of collaborative learning are widely researched and advocated throughout literature (Lehtinen 2003). Regardless of the varying theoretical emphasis in different approaches on collaborative learning (e.g. social constructivism), research clearly indicates that in many (not all) cases students learn more effectively through collaborative interaction with others. This motivates us to prepare remote labs for collaborative learning and to use them in distributed teaching scenarios together with simulation tools, hands-on laboratories and practical workshops. Our study suggests that there is a strong demand for research that seeks to create such a *mix*, where collaborative remote labs can play a significant role. This emphasis on collaboration adds new technical requirements to the design of remote laboratories. As a whole, there is a need to improve the usability of collaborative remote laboratory tools because otherwise learners may quickly get frustrated and stop working with it.

In the following sections we describe these issues in depth. We start with an analysis of laboratory environments, using it as an introduction to work out the characteristics of remote labs in comparison to other types of tools, such as hands-on and virtual labs. New results from collaborative work research are presented and we discuss implications for engineering education in general and lab courses in particular. Effective use of collaborative remote labs is based on a feeling of shared space, time and reality (presence), determined by technological and human factors. We will review related concepts and discuss lessons learned from our own research and prototype development. Before concluding, a case study is presented. This recent work involves the use of Mixed Reality (as opposed to 'pure' virtual reality) techniques to support seamless collaborative work between remote sites. We describe this and identify areas for future research.

Section 1: Remote laboratories in engineering education

In literature, numerous definitions of remote lab environments can be found (e.g. Bencomo 2004, Ma & Nickerson 2006). But nevertheless a universally applicable definition and mutual understanding of what exactly is meant when talking about a remote laboratory does not exist: the terms remote lab, web-lab, virtual lab, tele-lab, collaboratory or online lab are often used synonymously and inconsistently and in some publications there isn't even a clear distinction between those different types of tools. Researchers (e.g. Ma & Nickerson 2006) have convincingly argued that this confusion makes it difficult to evaluate the effectiveness of remote experimentation and its related technologies. The debate is also complex for other reasons. Almost all laboratories in science and engineering are mediated by computers. Accordingly, there are many lab devices nowadays which are operated via a computer based interface anyway. In such cases, the nature of accessing the lab equipment may not differ much, whether the student is collocated with the physical apparatus or is interacting remotely via a virtual interaction panel. Although it might be fruitful talking about the relative extent of remoteness or virtuality, it is also important initially to establish a proper taxonomy for later study. Thus, in order to ascertain what is actually meant by the aforementioned types of labs, we will in the first step differentiate between hands-on and virtual (simulated), local and distributed, and mono-user or multi-user environments. The following criteria allow us to establish a first orientation (see fig 1):

1. The nature of the lab equipment (physical or virtual).
2. The access-mode to perform a task (local or distant access).

user access / nature of equipment	local	distant
physical (real)	**hands-on lab**	**remote lab**
virtual (modelled)	**virtual lab**	**distributed virtual lab**

Figure 1: Laboratory environments

As regards these criteria, the general idea behind a *remote laboratory* is the ability to access physical laboratories or workbenches from distant sites by using a suitable communication infrastructure. In a remote laboratory the user (alone or as part of a team) and the laboratory setup are at different locations and participants work through a computer that is connected online to a real device. The typical scenario in education, for example, corresponds to learners that use the web to access the lab from their homes. On most occasions, their objective consists of carrying out a work assignment that is part of their study activities. However, it should be stressed that remote experimentation is not necessarily an educational activity. In industry, as well as in research centres, the remote control of devices through the Internet represents a unique opportunity to solve engineers' and scientists' needs to access apparatus or machinery from a distance. Another possible scenario consists of an institution that provides remote access to some form of equipment that may be too expensive to be acquired by an individual or even a small company (Eikas et al. 2002).

Remote labs can be a useful complementary educational resource to hands-on labs, as they allow monitoring or supervising a running experiment remotely. To get rid of geographic proximity restrictions has far reaching consequences for education. Networked facilities can be shared by students working from distant locations, 24 hours a day. But experimentation in situ with a plant or real object cannot be totally replaced by remote resources.

Hands-on labs, where students operate a real plant or manipulate real objects while being directly collocated with the tools and objects in the same room will remain existential in engineering education, because learning experiences in real-life situations are not only a key prerequisite for learning psychomotor skills, but also relevant for understanding theoretical concepts. The psychologist Piaget drew attention to this phenomenon long ago, when he described how cognitive development is generally rooted in the tactile interaction with the objects in their environment (Piaget 1963). Accordingly there is no doubt that hands-on labs and workshops play an important role in engineering education. Nersessian (1991) even goes so far as to claim that "hands-on experience is at the heart of science learning", and Ma & Nickerson (2001) emphasize that hands-on labs are important initially to establish the reality of remote laboratories or the accuracy of simulations for later study. Accordingly, the effectiveness of remote labwork is seen to be correlated to the directness of its link to the real world (Cooper et al. 2002).

As remote labs are always networked to physical objects, so called *virtual laboratories* are non-physical tools. Actually, they are simulated labs. Consequently, a virtual laboratory can be defined as a computer-based model of a real-life lab. They can be realized as local or distributed applications. Because a virtual lab consists of a computer program, which can easily be operated simultaneously by more than one user, it is at the same time a multi-user environment ready for collaborative lab work. The most important educational aspect of virtual labs is the reduced risk associated with operator errors, and the opportunity to experiment and practise without being exposed to hazards. That is why the virtual lab very often acts as an antechamber (e.g. for prelab assignment) to the real-world experiment, allowing the application and testing of theoretical knowledge and skills in a safe environment before trying out the same actions on real equipment.

*Distribute*d, or so called shared, laboratories introduce a category that allows sharing lab resources among each other. This kind of infrastructure enables a wide spectrum of scenarios, including the case where different users and lab facilities may be distributed among numerous locations (Ferreira, Müller 2004) (see fig 2).

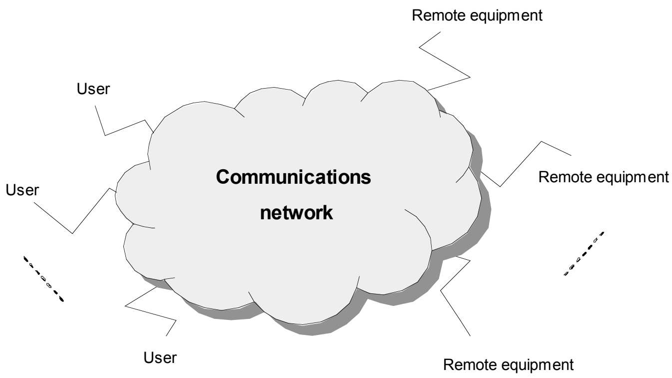

Figure 2: Distributed remote lab scenario (Ferreira, Müller 2004)

Notably, the World Wide Web brought new possibilities to the educational community in terms of distributing and sharing lab resources. As regards this aspect, Antsaklis et al. (1999) describes the variety of shared labs: "A shared laboratory can mean two or more departments sharing equipment and coordinating the development of experiments. It can mean the development of an integrated network of centralized laboratories…, or it can mean sharing laboratories across campuses and across universities. Shared laboratories within individual colleges or universities, as well as shared laboratories among different universities, make more efficient use of resources, increase exposure of students to the multidisciplinary nature of control, and promote the interaction of faculty and students across disciplines".

A special and very important category of shared remote laboratory is the one where geographically distributed users can *simultaneously* access and control lab facilities in real time to perform learning or working tasks in a collaborative way. This is actually the category of distributed labs that we focus on in this publication and that we call a *collaborative remote laboratory*. Consequently a collaborative remote lab is a multi-user environment that allows a team to be working on the same lab assignment across distributed and remote sites concurrently. A collaborative remote lab may be consisting of a grid of physical labs facilities distributed among various locations.

Section 2: Perspectives from CSCW research

Computer Supported Cooperative/Collaborative Work (CSCW) reflects the reality of an increasing number of work situations. CSCW means when two or more people, who are not located at the same place, organize their common work activities by means of computer based tools and services. Many authors agree that it is meaningful to differentiate between cooperation and collaboration. Roschelle & Teasley (1995) give a widely accepted definition of collaborative versus cooperative work: “Cooperative work is accomplished by the division of labour among participants, as an activity where each person is responsible for a portion of the problem solving...”, whereas collaboration involves the ”... mutual engagement of participants in a coordinated effort to solve the problem together”. The distinction is based on different ideas of the role and participation of individual members in the activity. Also it makes sense to further distinguish between synchronous (i.e. working together at the same time) and asynchronous activity. Contrary to cooperation, collaboration is “ ...a coordinated, synchronous activity that is the result of a continued attempt to construct and maintain a shared conception of a problem“ (Dillenbourg et al. 1995).

Computer supported collaboration introduces a change in scientific and engineering work by divorcing collaboration from physical locations. Usual face-to-face work is going to be replaced, at least partly, if not totally, by computer mediated collaboration. Distributed design and production across remote sites are global trends in industry for saving time and costs. For example, services for remote repair, diagnostics and maintenance (RRDM) is meanwhile widespread, and aid in expanding manufacturing facilities both nationally and internationally (Biehl et al. 2004). The integration of technology with physical space will make computing less visible or transparent in future work environments (Fernando et al. 2003, Schaffers et al. 2005, Collaboration@Work 2006). Ultimately, people will work seamlessly in distributed work spaces with documents, scientific models and virtual prototypes, both alone and collaboratively with distant colleagues as if they were in the same space. Ubiquitous, pervasive and calm technologies will extend human ability beyond limitation of time and physical constraints. Companies are going to implement technologically integrated spaces, housing large embedded displays, networked furniture, wireless devices for tracking people and remote access to supercomputers etc.

A key motivation behind these challenges is to enable continuity of collaborative work, through pervasive access to all kind of information, remote facilities, and groupware services. It is a perspective on collaborative work that has clear benefits for organisations that require individuals to work electronically away from the principal site but still maintain a collaborative link with their colleagues. Researchers (e.g. Bohn et al. 2005), who have developed a more critical perspective of this kind of *anyone, at any place, at any moment collaboration* argue that ubiquitous computing or ambient intelligence could leave the users without control. There seems to be a strong need for a balanced view emphasizing how ambient systems need to be visible, how they can be deconstructed, how coherence can be achieved, how they can provide stability and understandability, and in particular how users can stay in control when dealing with a large number of autonomous components (Erbe 2006).

Central to collaborative work as well as collaborative learning are social, motivational, and emotional factors that are difficult to implement in computer applications. In everyday face-to-face communication, social, motivational, and emotional meanings are mediated by using different verbal and non-verbal communication acts (Lehtinen 2003). If information and communication technology is designed to replace these activities completely by computer-mediated communication, it can radically reduce the effectiveness of collaboration because of the limited repertoire of communication modalities. From CSCW research, we know that collaboration tools often require that users carry out activities which do not naturally belong to their tasks, or else the tools foster actions that are rare in normal work and do not support users carrying out their most frequent activities (Lehtinen et al. 1998). One of the main challenges for the development of technologies for collaborative work is to create tools which can meet the motivational demands and particularly support the sharing of informal and tacit knowledge. As Hollan and Stornetta (1992) point out, CSCW tools must enable users to go "beyond being there" and enhance the collaborative experience. When this is not the case, users will avoid using the tool.

Nevertheless, and despite all problems we are faced with CSCW, distributed collaborative work is a global trend in industry. Thus, future engineers, technicians and workers are demanded to acquire some kind of competences and professional skills to work effectively in distributed collaborative work settings. In the field of engineering this requires not only competent operating of tools and systems for collaborative design, diagnosis, maintenance, monitoring and repair, but above all the ability to communicate effectively with others (e.g. customers, users, appliers) within computer mediated environments. Moreover, the future work force has to solve the 'mutual knowledge problem', for example by integrating the know-how of others in order to accomplish the work tasks using appropriate methods and tools. Special focus must lie on accessing distributed information from different actors and stakeholders (e.g. suppliers, customers and manufacturers) via global networks.

Although the hierarchy and the division of labour is simpler in educational than in work organisations, we believe that the aforementioned research results in relation to CSCW are applicable to the educational context. There are a reasonable amount of published studies showing positive learning effects when CSCW tools have been applied in educational settings. Generally, it is apparent that students do not only learn from tools and equipment, but from interactions with peers and teachers. There are, however, still many open questions and disagreement why collaborative learning methods affect achievement and even more importantly, under what conditions collaborative learning has these effects (Lehtinen 2003).

Section 3: Collaborative learning with remote labs

Reflecting our previous discussion about new demands in collaborative engineering, we could argue that the growth of shared infrastructure in real working live should have implications for pedagogy. For example, students who take up a career in engineering are very likely to participate in computer mediated collaboration at some point. We believe that remote laboratories are ideal tools for teaching distributive collaborative work skills, because they offer perspectives of shaping teaching scenarios which are close to practical engineering team work. This is a motivation to prepare available remote labs for collaborative learning and provide them in distributed teaching scenarios together with other tools and media. Our study suggests that there is a strong need for research that seeks to create such a *mix*, where collaborative remote labs can play a significant role.

If we take a closer look at remote laboratory-based teaching there are a few studies available focused on collaborative learning (e.g. Müller & Steenbock 2001, Tuttas et al. 2003, Böhne et al. 2005, Gillet et al. 2005). Most of this research gives evidence that well constructed group activities used in conjunction with remote labs could generate an added value in regard to team skills, language proficiency, and remote engineering competences. In respect to task time performance, research indicates that remote learners mostly need more time to perform a work assignment or experiment. Of course, this is not surprising at all, because those tasks that require a full multisense perception of the learning object – which is often the case – are effected by reduced perception, and learners need more time or are even not able to accomplish the task remotely. This could be an indicator that the tool is not suitable or that the task itself is not performable at all. But the reason could also be that the learners are not familiar enough with this type of assignment and need more exercise and practice.

If collaboration in shared work spaces is likely to be quite representative of how many engineers will work in the future, collaborative remote labs might be ideal tools to anticipate this in training and education. In conformance with these findings Ma & Nickerson (2006) suggest:

"… even if remote labs are not as effective as hands-on labs, the experience of working with geographically separated colleagues and specialized equipment may be educationally important enough to compensate for any shortcomings in the technology. It may be that students using remote laboratories will find different ways of collaborating, and the mode of collaboration they choose may affect what they learn from the laboratory experience".

As a result, we should determine that Ma's & Nickerson's observations are essential for the future discussion in our study.

Section 4: Sense of presence and reality within collaborative remote labs

As mentioned before, the pedagogical effectiveness of lab work is considered to be correlated to the directness of its link to the real world. Accordingly, remote labs are often criticized in that they are not able to provide authentic settings and interactions with real systems (Nejdl & Wolpers 2004). This is evident in single-user applications, but is even more critical in multi-user environments, where participants have to share objects remotely. For example, if students are in an

allocated lab seated around an experiment workbench, it is easy for them to look at the experiment set up while simultaneously be aware of the conversational cues of the other participants. But in a distributed and computer mediated work situation, user-interaction related problems, like loss of feedback or social interactivity may occur. Moreover, collaboration within remote lab spaces requires better synchronous communications tools, the possibility of passing the control to other users involved in a session or features for the management of different collaborative schemes and workflows. Consequently, there is a need to improve the usability of remote laboratory tools in this direction. Otherwise learners may quickly get frustrated and stop working with it. As remote labs separate users from their real workbenches and traditional tools the question is how to give learners the impression of being in the real lab working together and influencing reality?
In human-computer interaction (HCI) research, the feeling of being in a place is described as presence. Sheridan (1992) draws a distinction between three types of presence: physical, virtual, and telepresence. Physical presence can be characterized as “physically being there”. Virtual presence is “feeling like you are present in the environment generated by the computer”.

Section 4.1: Telepresence

The term telepresence coined by Minsky (1980) in connection with teleoperating systems for remote manipulation of physical objects. Telepresence describes a “feeling like you are actually there at the remote site of operation”, and characterizes the situation when someone experiences reality and presence over a distance (p. 120). “Telepresence enables a person to receive live sensory inputs from a distant environment and, under certain conditions, to telemanipulate the objects there” (Zhao 2003). In principle, the sense of telepresence is a feeling of shared space, time, and reality. According to Steuer (1992), telepresence refers to the mediated perception of an environment, which can be either a temporally or a spatially distant ‘real’ environment. Benford et al. (1998) describe classification criteria of shared-space approaches according to the dimensions of transportation and artificiality. They identified four major strands of technology using this classification (see fig. 3), where telepresence combines the remote and physical (Benford et al. 1998, p 193).

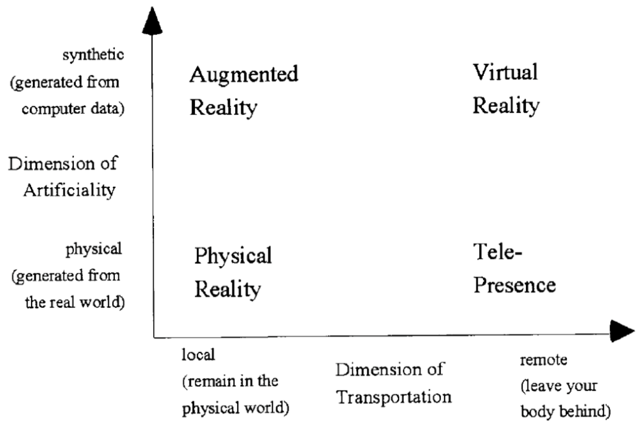

Figure 3: Broad classification of shared spaces according to transportation and artificiality (Benford et al. 1998).

Buxton stated that telepresence is a practical term, which describes "… the use of technology to establish a sense of shared *presence* or shared *space* among geographically separated members of a group" (Buxton 1993, p.816). When emphasizing the human aspect, we also have to focus on social and psychological factors of presence and reality, which we will briefly discuss in the following.

Section 4.2: From telepresence to social presence

As defined by Witmer and Singer (1998), the social and psychological category of presence refers to the feeling of being together, of social interaction in mediated spaces with other persons physically situated in another, perhaps remote, environment. The feeling of being socially present with another person at a remote location is described as social presence. Social presence is an important factor in order to communicate and collaborate efficiently. In distributed work settings social presence is difficult to provide, as humans have to cope with situations in which they cannot perceive all the information they have in face-to-face interaction.

The theory of social presence is originally derived from telecommunication research (Short et al. 1976) but met later with response from researchers of the HCI area (e.g. Sallnäs 2004). Short et al. (1976) state that social presence represents a synthesis of the following factors: expression, direction of looking, posture, touch, and nonverbal cues. Witmer and Singer (1998) relate the sense of social presence to immersion. Immersion is a mental state characterised by perceiving oneself to be enclosed by, included in, and interacting with an environment that provides a continuous stream of stimuli and experiences.

Factors that affect immersion include isolation from the physical environment, perception of self-inclusion in the shared virtual reality space, natural modes of interaction, and perception and control of self-movement. A computer mediated environment that produces a greater sense of immersion increases the level of presence.
Mixed Reality seems to be an approach to support social presence in collaborative remote environments, as it can enable co-located and distributed users to interact in distributed virtual spaces while viewing or even manipulating real world objects at the same time. Mixed Reality interfaces can overlay graphics, video, and audio onto the real world. This allows the creation of shared workspaces that combine the advantages of both virtual environments and seamless collaboration with the real environment. Information overlay may be used by remote collaborators to annotate the user's view, or may enhance face-to-face conversation by producing shared interactive virtual models. In this way, Mixed Reality techniques can produce a shared sense of presence and reality. Thus, Mixed Reality approaches would be ideal for multi-user collaborative lab and work applications. Later on in the next section, we will continue to discuss this aspect.

Section 4.3: Factors creating a sense of presence and reality

Enlund (2001) introduced a model, which describes the variables that determinate the sense of presence and reality in computer mediated environments (fig 4). The model is based on various theories and empirical findings. The terms "sense of presence" and "sense of reality" are used interchangeably in this concept. The difference is mainly one of subjective involvement: in certain cases users may perceive an environment as being real without having the feeling of being present in it. But the methods and means for stimulating and achieving these feelings are similar. Generally the sense of presence and reality is a feeling of shared space, time, presence, and reality. Enlund suggests to distinguish between the following major factors:

(1) the quality of the sensory environment presented to the recipient of information,
(2) the individual preconditions of the recipient her-/himself, and
(3) the characteristics of the contents of the mediated communication.

In the following, we will reflect on a few of those factors which seem to be especially important within our discussion.

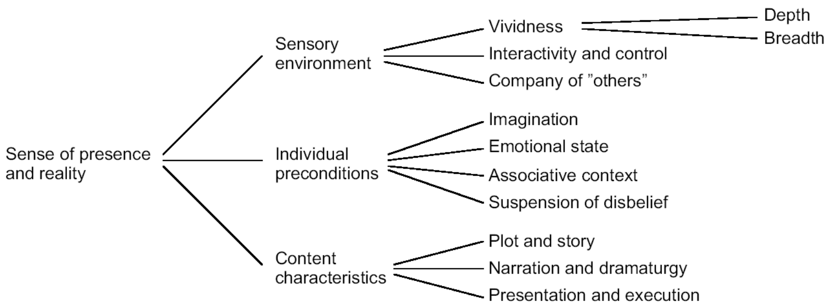

Figure 4: Factors creating a sense of presence and reality (Enlund 2001)

Sensory environment

From HCI research we know that the quality of sensory environment is of paramount importance. Steuer (1992) argues that at least two technological variables are most relevant: vividness and the degree of interactivity. Vividness is a cumulative function of the variety and richness of the sensory information, characterized by the sensory breadth and by the sensory depth. Interactivity is dependent on the extent of control that the user can execute and on the response that the environment offers. Interactivity is, like vividness, stimulus-driven and determined by the technological structure of the environment.

Although the vast majority of work in human-computer interaction often involves only our senses of sight and hearing, with sporadic forays into touch, future remote laboratories will mostly benefit from developments beyond video and sound (Bruns et al. 2005). Tangible and embedded interaction, augmented and mixed reality characterize ultimate technologies for further applications in collaborative remote engineering and lab work. Early key work in this area of research may be attributed to Weiser (1993), Fitzmaurice (1996), Ishii & Ullmer (1997), Milgram & Kishino (1994). For an overview see also Ohta, Y. & Tamura (1999).

In particular, and in relation with collaborative presence, there are several studies indicating that vividness and task performance can be positively influenced by the aforementioned techniques. For example, tangible user interfaces (Sallnäs 2004) or touch feedback with shared tangible objects (Griffin et al. 2005) improve task performance, making it both faster and more precise. In our own research related to collaborative tangible user interface and haptics we found similar results (Bruns et al. 2002, Hornecker 2002). Further work of Yoo & Bruns (2004) describes a mixed reality based environment with force feedback to support collaboration in distributed real and virtual tasks. The system is used to get more insight into tangible cooperation between humans, avatars, or in general real and virtual systems. It allows selected teleoperation of objects into reality and their functional connection to a simulation model. Augmented and Mixed Reality used in teleoperation of remote robots or other apparatus help to optimize easy and intuitive use from distant locations. A popular and early application is the MarsMap system demonstrated as part of the Mars Pathfinder mission in 1997 (Blackmon 1998). Friz (1999) developed a telerobot training application based on augmented reality for manipulator programming and control. Åkesson and Simsarian (1999) presented a prototype, called Reality Portal, which provides the ability to interactively explore a remote space inside a virtual environment. Several European projects have addressed the issues of applying augmented and mixed reality techniques as a medium for collaborative training and remote experimentation (Bruns et al. 2002, Kaufmann et al. 2006, Müller & Ferreira 2004).

Other more advanced technologies, like olfactory displays, could also enhance the sense of presence in next-generation lab environments. As smell can be critical to remote experimentation, for example in relation with a remote digital workbench, smelling smoke from an electronic circuit, can signal the user to interrupt a running experiment in time before the board is destroyed. Several attempts have been made to include olfactory displays in computer-mediated environments (Kaye 2004). Tobias Scheeles' master thesis at artecLab used low-cost technology for an olfactory display to stimulate presence in an artificial CAVE environment (Scheele 2006). Experimental research in computerized scent output reveals that emitting scent on demand, and creating accurate scents are not solved optimally in all cases. However, there are prototypes around (e.g. Yu et al. 2003), and even a commercial system from TriSenx (www.trisenx.com) one can use on one's desktop.

Besides visual, auditory, tangible, haptic and olfactory stimuli, another possible source of sensory stimulation is moving air. A few studies already investigate air as a source of feedback and sensation. Noel et al. demonstrated that the feeling of presence in a virtual environment could be enhanced by breeze. Similar results were documented by Pratsch (2006) in his diploma work at artecLab. He developed a so called 'Aero-Cave', an interface for a CAVE, which generates airflow caused by every natural movement of the user.

As a result, we should determine that the development of progressively sophisticated technologies can significantly enhance the sense of presence and reality in next-generation lab environments. Some of these concepts and technologies are still in a prototype stage, expensive, or cumbersome in use. However, they open exiting perspectives for new visions for collaborative lab spaces for the future.

Section 4.4: Authenticity and reality

One other aspect which has to be discussed in relation with remote lab learning is that of authenticity and reality. We must acknowledge that the pedagogical effectiveness of remote labs may be affected by the extent students actually believe in them (is it real or not?). As the reality of the remote hardware is only mediated by distance, users are required to suspend their disbelief to a certain extent. Accordingly, remote labs are sometimes criticized for their inability to provide an authentic link to real systems and apparatuses. However, is it the linkage to the real world that is important, or the belief in it? Thus, it is not amazing that the pedagogical effectiveness of a remote lab might be more or less influenced by the so called 'willing suspension of disbelief'. The phenomenon 'willing suspension of disbelief' is rather known: for example watching a television soap opera or reading a fascinating book often can encourage a kind of emotional realism for the viewer respectively the reader, respectively which only exists at the connotative rather than the denotative level (Enlund 2001). One may have the feeling that it is a true to-life story even when realising that it is completely unrealistic at the denotative level. But in order to fully enjoy the experience, it is most undoubtedly important to willingly suspend disbelief. Ma & Nickerson (2006) argue that "belief may be more important than technology" (p. 11) and moreover "students' preferences, and perhaps their learning performance, cannot be attributed to the technology of the laboratory alone". Consequently it seems to be important to study how students' mental activities are engaged in coping with the laboratory world: "Therefore, an understanding of presence, interaction, and belief may lead to better interfaces. Also, if belief proves important, then hybrid approaches might be contemplated, in which hands-on work is used at an early stage to build confidence in remote or simulated technology used in later teaching"(Ma & Nickerson 2006. p14).

When discussing the individual preconditions of learners we should also reflect on their affective experience with a new generation of entertainment technology. As our students play the latest computer games, they are already very familiar with the whole spectrum of immersive 3D environments, namely massively multiplayer online games (MMOs). The affective experience with this kind of environments cannot be matched by traditional e-Learning tools. This phenomenon needs more attention, because there is of course a relationship between presence and enjoyable, playful learning tools. Barfield and Weghorst (1993), for example, report that presence and task performance are strongly influenced by the mediating effect of enjoyment.

A few attempts had been made to integrate elements of immersive 3D environments in collaborative e-Learning tools. In artecLab, we developed a prototype for collaborative and synchronous modelling of pneumatic circuits. The environment provides a 3D interface and couples real artefacts with virtual counterparts. Users are building a physical model while the computer tracks these actions and assembles a corresponding virtual model. The virtual model can be used for further simulation studies. In addition, the system integrates chat, video and audio conferencing tools, plus the possibility to view other user actions as corresponding avatar movements (Ernst et al. 1999). Röhring and Bischoff (2003) presented a multiuser remote experimentation system using avatar techniques and 3D chat. Both approaches aim for a similar goal: to stimulate a shared sense of

presence and social presence through distributed controlled avatars (tele-actors) in connection with other communication tools and the possibility to interactively access remote hardware and facilities.
Virtual online worlds or MMOs offer the ability for numerous users to simultaneously act in the same shared virtual space. For example the 3D virtual world *Second Life* by Linden Lab (http://secondlife.com) offers considerable options for group work, which makes this environment interesting for collaborative learning. Users, called 'residents', communicate and collaborate on joined complex tasks, while they are able to generate new knowledge and shared expertise. In contrast to many other MMOs, *Second Life* has no predefined goals and users may adapt the environment for their own objectives by constructing and scripting new objects. This open character of *Second Life* has already attracted a number of education projects (Livingstone & Kemp 2006). Accordingly, it seems to be possible to link external lab hardware resources with *Second Life*. The ability to interactively access real labs within *Second Life* opens perspectives at the same time to use the full range of collaboration and groupware facilities provided. Using *Second Life* as a learning portal for accessing digital learning resources is already quite common. Moreover, an active community has started the project SLoodle (www.sloodle.com) to integrate the open source Virtual Learning Environment (VLE) platform Moodle with the 3D world of Second Life. If this project is successful, educators and learners will be able to create new environments for collaborative remote experimentation and work. However, we should not uncritically adapt Second Life and other MMOs for education. The same factors that support collaboration and social presence can promote addictive gaming behaviours that supersede learning activities such as exercise, social interaction, and concept work. Some educators even speculate that excessive involvement in computer games negatively impacts interpersonal relationships, scholarship and family life (Messerly 2004). Up to now, there are no real solid data supporting negative claims about MMOs, though. However, expanding e-Learning into the realms of immersive virtual worlds introduces numerous pedagogical, ethical and legal issues that we will have to confront.

Section 5: A case study: From remote labs to collaborative workspaces

In a series of case studies and experiments carried out at artecLab, we have investigated factors that determine the quality of presence and reality in collaborative working and learning environments. We have done this using primarily low budget technology. Within this publication we have already briefly reported on some of those experiments and on the indicative results they have produced. In the following we will describe recent work that involves the use of Mixed Reality (as opposed to 'pure' virtual reality) techniques to study how collaborative engineering between remote sites can be supported by Mixed Reality technologies. One of the main problems is to couple seamlessly distributed real and virtual objects which are in the action space of the users. To solve this, Bruns (2001) developed an interface technology for connecting real with virtual components of different kind. The interface, called *Hyperbond*, is a mechanism based on the translation between physical effort/flow phenomena and digital information, like analog/digital and digital/analog conversion. However it aims at a unified application oriented solution connecting the physical world with its virtual representation and continuation. The name *Hyperbond* has been chosen because of its relation to the description of dynamic systems with bond graphs, first introduced by Paynter (1961).

In a current case study we are implementing a prototype of a shared virtual and remote laboratory using the Hyperbond concept. The environment envisaged allows working collaboratively with real and virtual systems, consisting of parts which may be remotely distributed. Accordingly a remote physical laboratory workbench can be coupled with a local virtual workbench and vice versa. The system supports full hardware-in-the-loop functionality, allowing to build up complete electro-pneumatic circuits, which may be consist of distributed mixed physical and virtual electro-pneumatics.

Real and virtual workbenches are located in CAVE-like constructions (Computer Automatic Virtual Environment). We use CAVE's (Cruz-Neira et al. 1992) because remote and local participants can immerse into a common workspace for solving a joined task, such us collaborative tele-design or tele-maintenance. Every CAVE consists of a room-sized cube covered with canvases. The different images of other workspaces with the participants working in them are projected onto the canvas walls. The common virtual workbench and the real physical workbench are accessible via the Internet and also visualized in each CAVE. The projections are controlled by client computers connected to a central media server. As available CAVE´s are very expensive, we developed a low budget solution, which consists of wooden scaffoldings, ordinary video projectors and PC's. In comparison to commercial CAVE's our system offers nearly the same performance and provides a sufficient solution for research. The following figures show the arrangements used for the test cases. The basic architecture of the distributed CAVES is illustrated in Fig. 8.

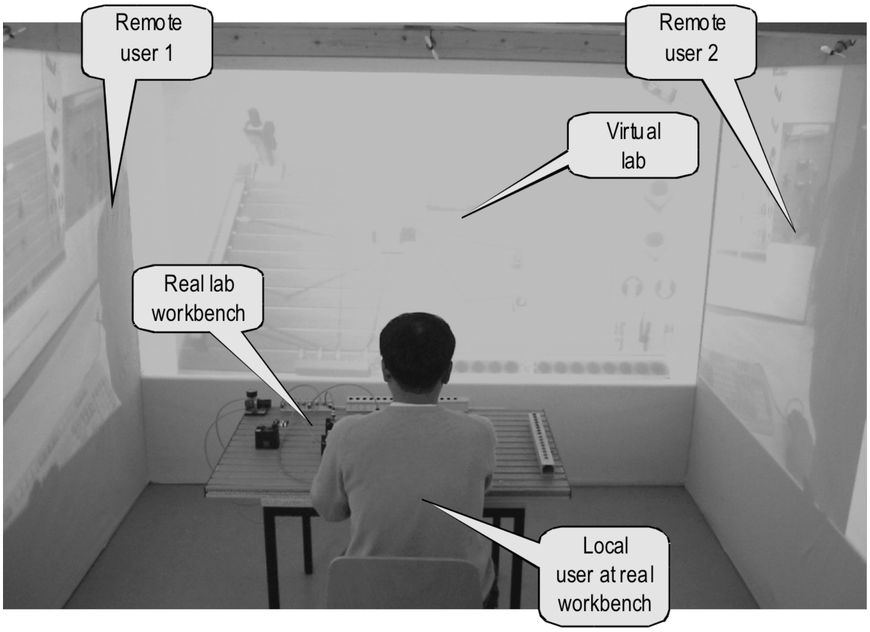

Figure 5: Workspace at the real workbench in a CAVE

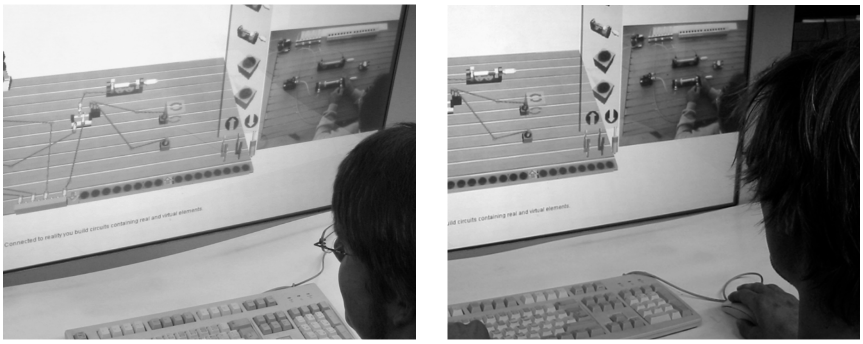
Figure 6: Two distributed users connected to the real workbench from remote

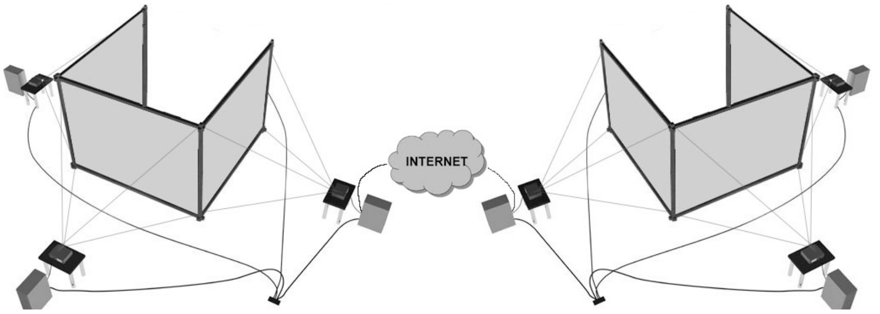

Figure 7: Distributed CAVE-based workspaces

The real and virtual workbenches were implemented as a Web Service to take advantage of web technology (e.g. easy accessibility, platform independence). A central module is the Mixed Reality (MR) Server which realizes this Web Service. The Web Service itself processes HTTP requests and also manages the sessions of all remote users. Relevant data belonging to a certain work session is stored on the server, such as virtual model data, support material and background information. The WWW front end consists of a HTML page including a Virtual Construction Kit (VCK) and a video stream window. The VCK itself is a VRML based tool for assembling virtual worlds: by dragging and dropping objects from a library onto the virtual workbench new objects (e.g. cylinders, valves, and switches) can be added. Each of these objects has connectors which can be linked to other ones. Links can either be tubes (air pressure) or wires (electricity). Connections between real and virtual workbench elements were realized by the aforementioned Hyperbond technology. First experience gained in this case study has already illuminated how future engineering workspaces and laboratories could be structured. Several key features of tomorrow's remote laboratories can be identified, including support for freely exploring a phenomenon and its appearance in various applications and contexts, means for a universal mixing of real and virtual objects, and distributed work on tasks in a multi-modal and multi-user way.

Conclusion

Our study may provide a starting place for researchers involved in the discussion about the role and value of collaborative remote laboratories in engineering education. A sense of presence and reality can be achieved not only in hands-on, but also in collaborative remote labs. The basic factors of generating feelings of presence and reality in computer-mediated labs are related to the sensory environment, the individual preconditions and other learner's human factors. Perhaps with the proper mix of technologies we can find solutions that meet the requirements of engineering education by using hands-on labs, virtual labs (simulations), and remote labs as complementary educational tools to reinforce conceptual understanding, while at the same time providing enough room for experiential learning and reflection. Our discussion suggests that there is a need for future research that seeks to create hybrid learning spaces, which might be stimulated by more case studies and experimental research. Finally, it is obvious that students do not gain knowledge and skills from technology only. As stated by Ma & Nickerson (2006): "… students learn not only from equipment, but from interactions with peers and teachers. New technologies may call for new forms of coordination to augment or compensate for the potential isolation of students engaged in remote learning".

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References

Åkesson, K., Simsarian, K. (1999): Reality portals. In Proceedings of the ACM Symposium on Virtual Reality Software and Technology (London, United Kingdom, December 20 - 22, 1999). VRST '99. ACM Press, New York, NY, pp. 11-18.

Antsaklis, P., Basar, T., DeCarlo, R., Harris, N., Spong, M., Yurkovich, S. (1999): Report on the NSF/CSS Workshop on new directions in control engineering education. IEEE Control Systems Magazine, 19(5), pp. 53–58.

Barfield, W., Weghorst, S. (1993): The sense of presence within virtual environments: A conceptual framework. In G. Salvendy & M. Smith (Eds.), Human-computer interaction: Software and hardware interfaces (pp. 699-704). Amsterdam: Elsevier.

Bencomo, S. D. (2004): Control Learning: Present and Future. Annual Reviews in Control 28 (2004), pp. 115-136.

Benford, S., Greenhalgh, C., Reynard, G., Brown, C., Koleva, B. (1998): Understanding and constructing shared spaces with mixed-reality boundaries, ACM Transactions on Computer-Human Interaction (TOCHI), v.5 n.3, pp.185-223, Sept. 1998

Biehl M., Prater, E., McIntyre, J. R. (2004): Remote Repair, Diagnostics, and Maintenance. Communications of the ACM, Vol. 47, No. 11, November 2004.

Billinghurst, M., Kato, H. (1999): Collaborative Mixed Reality. Proceedings of the First International Symposium on Mixed Reality (ISMR '99). Mixed Reality – Merging Real and Virtual Worlds, pp. 261-284. Berlin: Springer Verlag.

Blackmon, T. (1998): MarsMap – Virtual Reality for Mars Pathfinder. [http://scan.berkeley.edu/people/ttb/MarsMap/marsmap.html, accessed: 23. March 2007).

Bohn, J., Coroama V., Langheinrichs, M., Mattern, F., Rohs, M. (2005): Social, Economic, and Ethical Implications of Ambient Intelligence and Ubiquitous Computing. In: W. Weber, J. Rabaey, E. Aarts (Eds.): Ambient Intelligence. Springer-Verlag, ISBN 3-540-23867-0, pp. 5-29, 2005

Böhne, A., Faltin, N., Wagner, B. (2005): Evaluation of distributed versus collocated group work in a remote programming laboratory". In proc. Interactive Computer Aided Learning conference (ICL 2005), Villach, Austria, September 2005.

Bruns, F. W. (2001): Hyperbonds – enabling mixed reality. Technical Report ARTEC paper 82, ARTEC, University of Bremen. Bremen 2001.

Bruns, F. W. et al. (2002): Distributed Real and Virtual Learning Environment for Mechatronics and Tele-Service. Final Report of EU-Project DERIVE, artec-paper 102, Bremen [online: http://arteclab.artec.uni-bremen.de/publications/artec-02-Bruns-artec-paper102DERIVEFinalReport.pdf, accessed: 25. Jan. 2007]

Bruns, F. W., Erbe, H.-H., Faust, M. (2005): Engineering future laboratories. In: Müller, D. (ed.) (2005): MARVEL- Mechatronics Training in Real and Virtual Environments. Concepts, Practices, and Recommendations. Impuls Vol. 18. Published by Nationale Agentur für Bildung in Europa beim BiBB. Bonn 2005

Buxton, W. A. S. (1993): Telepresence: Integrating Shared Task and person Spaces. In Baecker, R. M. (ed.) Readings in Groupware and Computer-Supported Cooperative Work. San Mateo, CA: Morgan Kaufmann, pp. 816–822.

Collaboration@Work (2006): European Commission (Ed.), Collaboration@Work – The 2006 report on new working environments and practices. Luxembourg: Office for Official Publications of the European Communities.

Cooper, M., Donelly, A., Ferreira, J. M. (2002): Remote controlled experiments for teaching over the Internet: A comparison of approaches developed in the PEARL project. In Proceedings of the ASCILITE Conference

2002. Auckland, New Zealand. UNITEC Institution of Technology, M2D.1-M2D.9.

Cruz-Neira, C., Sandin, D. J., Defanti, T. A., Kentyon, R. V., Hart, J. C. (1992): The CAVE: Audio Visual Experience Automatic Virtual Environment. Communications of the ACM, 1992, Vol. 35 (6), pp. 65.

Dillenbourg, P., Baker, M., Blaye, A., O'Mailley, C. (1995): The evolution of research on collaborative learning. In P. Reimann & H. Spada (Eds.) Learning in humans and machines. Towards an interdisciplinary learning science. S. 189-211. Oxford: Elsevier.

Eikaas, T. I., Schmid, C., Foss, B. A., Gillet, D. (2002): A Global Remote Laboratory Experimentation Network and the Experiment Service Provider Business Model. Conference on e-Work and e-Commerce (e2002), Prague, Czech Republic.

Enlund, N. (2001): Being virtually there – reality and presence in mediated learning. Proceedings of the 2001 International Conference on Telecommunications for Education and Training, Charles University, Prague, 2001, pp. iv-ix.

Erbe, H.-H. (2006): Ubiquitous Automation - A Goal for Future Workplaces? 9th IFAC Symposium on Automated Systems Based on Human Skill and Knowledge, Nancy, 22.-24. May, 2006.

Ernst, H., Schäfer, K., Bruns, W. (1999): Creating Virtual Worlds with a Graspable User Interface. Interactions in Virtual Worlds. Proceeding of the Twente Workshop on Language Technology, TWLT 15, Enscheide: Universiteit Twente, pp. 45-57.

Ferreira, J. M., Müller, D. (2004): The MARVEL EU project: A social constructivist approach to remote experimentation. 1st Remote Engineering and Virtual Instrumentation International Symposium (REV'04), Villach (Austria), 28.– 29. September 2004

Fernando, T. et al. (2003): A Strategic Roadmap for Defining Distributed Engineering Workspaces of the Future, European Commission, Brussels. [http://www.avprc.ac.uk/fws/final_roadmap.doc, accessed: 28. Jan. 2007]

Fitzmaurice, G. W. (1996): Graspable User Interfaces, Ph.D. Thesis, Dept. of Computer Science, University of Toronto. [http://www.dgp.toronto.edu/%7Egf/papers/Thesis.gf.final.pdf, accessed: 28. Jan. 2007]

Friz, H. (1999): Design of an Augmented Reality User Interface for an Internet based Telerobot using Multiple Monoscopic Views. Diploma Thesis, Institute for Process and Production Control Techniques, Technical University of Clausthal, Clausthal-Zellerfeld, Germany. [http://telerobot.mech.uwa.edu.au/Information/Friz-Thesis.pdf, accessed: 27. Jan. 2007]

Gillet, D., Nguyen-Ngoc, A.V., Rekik, Y. (2005): Collaborative Web-based Experimentation in Flexible Engineering Education. IEEE Transactions on Education, Special issue on Web-based Instruction, Vol. 48, No. 4, 2005, pp. 696-704

Goertz, R., Thompson, R. (1954): Electronically controlled manipulator. Nucleonics, 1954.

Goldberg, K. et al. (2000): Collaborative Teleoperation on the Internet, IEEE ICRA 2000. San Francisco, CA. April, 2000.

Griffin, W. B., Provancher, W. R., Cutkosky, M. R. (2005): Feedback strategies for telemanipulation with shared control of object handling forces. In: Presence: Teleoperators and Virtual Environments. Vol. 14, Issue 6 (December 2005). pp. 720 – 731.

Hollan, J., Stornetta, S. (1992): Beyond Being There. In Proceedings of CHI ’92, 1992, New York: ACM Press, pp.119-125.

Hornecker, E. (2002): Understanding the Benefits of Graspable Interfaces for Cooperative Use. In: Proceedings of Coop'2002 (Fifth International Conference on the Design of Cooperative Systems) in SAINT RAPHAËL, 4 - 7 june 2002. IOS Press, pp. 71-87.

Hornecker, E. (2004): A Framework for the Design of Tangible Interaction for Collaborative Use. Paper at the Danish HCI Symposion, University of Aalborg, Nov. 16. HCI Lab Technical Report no 2004/1. pp.57-61. [http://www.ehornecker.de/Papers/DanishHCI.pdf, accessed: 15. Jan. 2007]

Homepage of TriSenx Holdings, Inc.: http://www.trisenx.com/

Ishii, H., Ullmer, B. (1997): Tangible bits: towards seamless interfaces between people, bits and atoms, Proceedings of the SIGCHI Conference on Human Factors in Computing Systems, Atlanta, USA, 1997.

Kaufmann, H., Csisinko, M., Totter, A. (2006): Long Distance Distribution of Educational Augmented Reality Applications to appear in Proceedings of the Eurographics 2006, annual main conference of the European Association for Computer Graphics, Vienna, 4-9 September, 2006.

Kaye, J. (2004): Making Scents: aromatic output for HCI. interactions 11, 1 (Jan. 2004), pp. 48-61.

Lehtinen, E. (2003): Computer supported collaborative learning: An approach to powerful learning environments. In E. De Corte, L. Verschaffel, N. Entwistle & J. Van Merriëboer (Eds.), Unraveling basic components and dimensions of powerful learning environments (pp. 35-53). Amsterdam: Elsevier.

Lehtinen, E., Hakkarainen, K., Lipponen, L., Rahikainen, M., Muukkonen, H. (1998): Computer supported collaborative learning: A review. [http://suvi.kas.utu.fi/papers/clnet/clnetreport.html, accessed: 21. Jan. 2007]

Livingstone, D., Kemp, J. (2006): Massively multilearner: recent advances in 3D social environments. omputing and Information Systems Journal, School of Computing, University of Paisley, Volume 10, No 2, May 2006.

Ma, J., Nickerson, J. V. (2006): Hands-on, Simulated and Remote Laboratories: A Comparative Literature Review", ACM Computing Surveys, (38:3) Article No. 7, 2006, pp 1-24.

Mason, R. (1994): Using Communications Media in Open and Flexible Learning. London: Kogan Page.

Messerly, J. G. (2004): How computer games affect CS (and other) students' school performance. Commun. ACM 47, 3 (Mar. 2004)

Milgram, P., Kishino, A. F. (1994): Taxonomy of Mixed Reality Visual Displays. IEICE Transactions on Information and Systems, E77-D(12), pp. 1321-1329, 1994.

Minsky, M. (1980): Telepresence. In: Omni, June 1980, pp. 45-51.

Müller, D. (ed.) (2005): MARVEL- Mechatronics Training in Real and Virtual Environments. Concepts, Practices, and Recommendations. Impuls Vol. 18. Published by Nationale Agentur für Bildung in Europa beim BiBB. Bonn.

Müller, D., Ferreira, J. M. (2004): MARVEL: A Mixed Reality Learning Environment for Vocational Training in Mechatronics. In: Grew, P./Valle, G. (Eds.): T.E.L '03 Proceedings: International Conference on Technology-enhanced Learning (November 2003). Milano, Italy: Hugony Editore 2004, pp. 65-72.

Müller, D., Steenbock, J. (2003): Abschlussbericht Modellversuch Telemediale Lernumgebungen für berufliche Schulen am Beispiel des neuen Berufs Mechatroniker/-in (TELLME). Bremen [http://www.tellme.uni-bremen.de/pool/Abschlussbericht.pdf, accessed: 15. Jan.2007]

Nejdl, W., Wolpers. M. (2004): European E-Learning: Important Research Issues and Application Scenarios. Proc. ED-Media 2004, Lugano, Switzerland, June 2004.[http://www.kbs.uni-hannover.de/Arbeiten/Publikationen/2004/edmedia04.final.pdf, 15. Jan.2007]

Nersessian, N. J. (1991): Conceptual change in science and in science education. In History, Philosophy, and Science Teaching, M. R. Matthews, Ed. OISE Press, Toronto, Canada, pp. 133–148.

Noël, S., Dumoulin, S., Whalen, Th., Ward, M. Stewart, J. A., Lee, E. A. (2004): Breeze Enhances Presence in a Virtual Environment, Proceedings of the 3rd IEEE International Workshop on Haptic, Audio, and Visual Environments and their Applications - HAVE 2004, Ottawa, 2-3 October 2004, pp. 63-68.

Ohta, Y., Tamura, H. (eds.) (1999): Mixed Reality - Merging Real and Virtual Worlds, Springer Verlag, Berlin, 1999, pp. 1-16.

Paynter, H. M. (1961): Analysis and Design of Engineering Systems, MIT Press, Cambridge, MA.

Piaget, J. (1963, 2001): The psychology of intelligence. New York: Routledge.

Pratsch, D. (2006): The Aero-Cave Extension For Mixed Reality Collaboration. Proc. 12th IFAC Symposium on Information Control Problems in Manufacturing, 17-19 May, Saint-Etienne, France.

Roschelle J., Teasley S. D. (1995): The construction of shared knowledge in collaborative problem solving. In: O'Malley C.E. (ed.): Computer Supported Collaborative Learning, Springer Verlag, Heidelberg 1995, pp. 69-97.

Röhrig, C., Bischoff, A. (2003): Web-based Environment for Collaborative Remote Experimentation. Proceedings of the 42nd IEEE Conference on Decision and Control Maui, Hawaii USA.

Sallnäs, E.-L. (2004): The Effects of modality on social presence, presence and performance in collaborative virtual environments. Ph.D. thesis, TRITA-NA-0404. NADA, KTH, Stockholm Sweden. 2004. [http://www.lib.kth.se/Sammanfattningar/sallnas040324.pdf , accessed: 26. Jan. 2007]

Schaffers, H., Prinz, W., Slagter, R. (2005): Mobile and location-aware Workplaces and global value Networks: a strategic roadmap. Collaborative networks and their breeding environments. Springer Verlag, NY, 2005, pp. 425-436.

Scheele, T. (2006): Konzeption und Entwicklung eines olfaktorischen Displays für eine Computer Automatic Virtual Environment (CAVE). Diplom Master Thesis. University of Bremen.

Sheridan, T. B. (1992): Musings on Telepresence and Virtual Presence. In : Presence: Teleoperators and Virtual Environments, 1 (1). Pp. 120-126.

Short, J., Williams, E., Christie, B. (1976): The social psychology of telecommunications. Wiley, London.

Steuer, J., (1992): Defining virtual reality: dimensions determining telepresence. Journal of Communication, 42(4), pp. 73-93.

Tuttas, J., Rütters, K., Wagner, B. (2003): Telepresent vs. Traditional Learning Environments - A Field Study. International Conference on Engineering Education (ICEE-2003), July 22-26, 2003, Valencia, Spain.

Weiser, M. (1993): Some Computer Science Issues in Ubiquitous Computing. Communications of the ACM, Vol. 36, No. 7, pp. 74-78.

Witmer, B. G., Singer, M. J. (1998): Measuring presence in virtual environments: A presence questionnaire. Journal of Presence: Teleoperators and Virtual Environments, 7(3), pp. 225-240.

Yoo, Y. H., Bruns, F. W. (2004): Realtime collaborative Mixed Reality Environment with Force Feedback. 7th IFAC Symp. Cost Oriented Automation, Ottawa.

Yu, J., Yanagida, Y., Kawato, Sh., Tetsutani, N. (2003): Air Cannon Design for Projection-Based Olfactory Display, Proceedings of ICAT 2003 (The 13th International Conference on Artificial Reality and Telexistence), Tokyo, Japan, pp. 136-142, December 2003. [http://www.mis.atr.jp/~yanagida/pub/ICAT2003_yu.pdf, accessed: 25. Jan. 2007]

Zhao, S. (2003): Toward a taxonomy of copresence. Presence: Teleoper. Virtual Environ. 12, 5 (Oct. 2003), pp. 445-455.