Collaborative Environment Architecture Proposal: A study of virtual environments for learning purposes in control engineering

F. M. Schaf[1], C. E. Pereira[1] and D. Müller[2]
[1] Universidade Federal do Rio Grande do Sul / Dep. Engenharia Elétrica, Porto Alegre, Brazil
[2] Universität Bremen /ArtecLab, Bremen, Germany

***Abstract* — This work presents studies towards an architecture for Computer Supported Collaborative Environments (CSCE) to aid education and training in the control engineering. The expansion of social networks, virtual environments and Web technologies such as Web 2.0 has shed the light on learning technologies. Employing virtual worlds as breeding grounds to create an infinite range of learning and didactical materials are becoming more and more common as educational institutions realize the hidden potential of this endeavor. Despite several efforts and various implementations there are few standardizations or studies of interoperation between most of the tools and technologies available for CSCEs. This study focuses directly on a reference model architecture undisclosed when developers implement their solution to this complex theme. Presented are the some relevant technologies available and a possible link scheme between then. Concepts like: remote experiments to enhance learning; autonomous tutoring; and collaboration awareness support; integrated to CSCEs are described. As results, case studies and a prototype are presented with each chosen technology discussed.**

***Index Terms* — CSCL, CSCW, Remote Experiments, Mixed Reality.**

I. INTRODUCTION

Since it has been recognized that skilled engineers are one of the main elements for the development of innovative products and services, as well as for the optimization of production processes, to ensure high productivity and quality, most developed countries have treated this subject as a key aspect of their educational strategy. Considering control engineering education, a key issue is the reduction of the gap between classical theoretical courses and real industrial practice. Another key issue is to decrease the drop-off rate of engineering courses motivating students with collaborative state of the art technologies.

Unfortunately, to reproduce real industrial plants in an academic environment are not a trivial task as they are, in general, very expensive (in terms of acquisition, installation, operation, and maintenance costs). Furthermore, safety constraints always restrict the access of costly equipments that are only available for research and not in undergraduate academic laboratories courses. This way, most of them are structured only as small-scale experiments with little connection to industrial reality.

Within this context, industrial lab facilities made accessible via Web – therefore available at flexible times to a larger number of individuals – help to improve the overall cost-effectiveness of those solutions. Moreover they offer perspectives of shaping teaching scenarios, which are close to practical engineering team-work.

Very little has changed in the last one hundred years in the way that educators instruct students [1]. The system still holds fast to the age-old delivery method of the solitary scholar. This representation of teaching has been the most dominantly used option for the past several decades with universities and colleges as one section of schooling in which this traditional education method has been applied and adhered too studiously. Many of the newer methods of education that are emerging differ from conventional methods by the inclusion of online learning and Web based instruction, which is attracting the attention of many universities.

The online learning is tight related to other common topics like: CSCL and CBT (Computer Based Training). All these topics are used in distance education and employ concepts of active learning [2, 3], distributed learning [4] and team learning [5]. Active learning can be also classified as “learning by doing”, “self learning” and, when related to experiments (or laboratories), “hands-on learning”. Distributed learning is obviously related to the space flexibility that the distance education offers. The last, team learning, when users are synchronously learning together, is called collaborative learning.

The availability of remote experiments is not a sufficient condition to ensure success in learning. Stand-alone remote experiments without connection to adequate learning material usually lead students to the use of a trial and error strategy, which has a lower learning impact than originally expected [6] and decrease the added value of this alternative solution. Additionally, remote facilities are available 24-7 increasing the demand in the number of faculty members and tutors required to provide on-line guidance.

Still focusing learning technologies, it is widely believed that collaborative experiences are powerful drivers of cognitive processes and can significantly enhance learning efficiency. There are researches advocating that well constructed group activities used in conjunction with remote labs generate an added value in regard to team skills and remote engineering competences [7]. 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. These interaction also leads to motivation, another key aspect in the development of learning technologies.

How to effectively use computer technologies to support people in their learning (and also work), in particular when doing collaborative activities with coordination constraints is a topic that has been extensively researched for several years. Researchers recognize that this is not only a technological challenge but an organizational and social topic [8, 9]. However, only recently a major shift of focus on the difference between cooperation and collaboration occurred. The former being some kind of protocol to avoid conflicts and provide harmonic synchronization of task oriented work (assembly line model), whereas the later being a struggle for new products, tools, work-processes and a higher quality of all (creative workgroup model) [10].

Following this trend is not difficult to foresee a large spread of implementations of Computer Supported Collaborative Environments (CSCEs) in the scientific community. A research study of such environment capabilities and interoperability is therefore highly required. This work tries to comprise some studies and proposes a architecture for CSCE with relevant technologies and concepts aimed to education in engineering control.

The remainder of this paper is organized as follows: Section 2 presents virtual collaborative environments background theory; Section 3 describes collaboration in labs employed in education via Web; in section 4, briefly presents most prominent correlated state of the art works; the Section 5 describes the proposed architecture; Section 6 outlines developed case studies and a prototype for validating the proposed environment architecture. Finally, Section 7 quickly trends future works and Section 8 draws conclusions.

II. Virtual Collaborative Environments

Virtuality among several other utilities aims to close up dispersed or distributed users in a common locus. This *site* called commonly as environment is not physically real but virtual. Two well-known acronyms are directly related to virtual environments: the MUVEs (Multi-User Virtual Environments) and the MMORPG (Massively Multiplayer Online Role-Playing Game). While the first is a more generic term associated to all kinds of implementations of virtual worlds, the second is specifically employed in the entertainment field. There are several types of virtual environments that can be classified in areas of applications: work, learning, social and entertainment.

To achieve higher levels of human-human interactions, which are required to solve complex engineering problems, a strong support of collaboration and multi-perspectivity is required. Most of the MUVEs allow and facilitate collaboration among users. The following subsections describe with more details three types of environments in relevance with this work.

A. Learning Environments

Virtual collaborative environments applied in education are commonly called CSCL Environments [11]. Concepts of collaboration are closely related to learning. On collaborative activities humans interact employing self-critiquing (reflection), inquiring and arguing skills; these skills propel the knowledge building. This is the very essence of the (social) constructivism pedagogy employed nowadays in virtual environments and even in some special dedicated schools.

CSCL is a major method for bringing the benefits of collaborative and cooperative learning to users of distance learning via networked computers, such as the courses offered via the Internet. The purpose of CSCL is to scaffold or support students in learning together effectively. It supports the communication of ideas and information among learners, collaborative accessing of information and documents, and instructor and peer feedback on learning activities. Also supports and facilitates group processes and group dynamics in ways that are not achievable by face-to-face communication – such as having learners label aspects of their communication.

Like many educational activities, it is difficult to evaluate the effectiveness and efficiency of CSCL activities. Historically, the lack of evidence that technological innovations have improved learning in formal education highlights the need for evidence of whether, how and when expected improvements in learning take place. Computers have become important in this, with education related personnel and institutions around the world setting goals of increasing student access to computers and the Internet. However, the ability to combine these two ideas (computer support and collaborative learning, or technology and education) to effectively enhance learning remains a challenge [11].

It is important to mention that the use of VCEs does not necessarily exclude the traditional education. A mixture of the traditional and the CSCL is also much more common and related in the literature as *blended learning*. This blending brings up advantages to the traditional education offering technology related aspects to learning that are nowadays undeniable and advocated even from the most backward educators.

Virtual Learning Environments or Learning/Course Management System (LMS/CMS) are the most common tools employed for organize digital media learning objects/materials in the Web. Perhaps one of the most common free VLE implementation is MOODLE [12]. MOODLE is an open source project that is based on the social constructivism pedagogy. Most VLE implementations aid teachers with sufficient abstraction and intuitive graphical tools to create, host and link their didactic materials. They also provide user control and logging information that help to trace users' interactions.

B. Working Environments

Environments with work purposes, generally related to the term CSCW, are characterized to join task forces into common projects. Based on the literature, five levels of work coupling were identified: light-weighted interactions, information sharing, coordination, collaboration, and cooperation. Light-weighted interactions are only loosely tied to the work itself. Coordination, collaboration, and cooperation are much more tightly coupled than the previous two. Coordination requires group members to coordinate both the activities and communication. Collaboration levels of work coupling involve group members who work toward a common goal. They often are performing separate tasks that have a high degree of interdependence, but work is still done by individual members. They share goals, tasks, and a desire to maintain a high state of shared knowledge. Cooperation is the highest level of work coupling, and it demands the greatest amount and highest quality of communication. People at this level of work coupling have shared goals, common plans, shared tasks, and significant consultation with others about how to proceed with the work.

As work moves from the 3 Cs Model: coordination (also referred as communication), collaboration, to cooperation; team coordination becomes a significant aspect of the group work [13]. This way coordination can only occur if people are aware. Common ground is the product of joint awareness or mutual knowledge, and grounding behaviors is the process of maintaining joint awareness [14].

Working environments that involve synchronous multi-users activities often use a common shared workspace to help in online collaboration.

C. Social Environments

While software may be designed to achieve closer social ties or specific deliverables, it is hard to support collaboration without also enabling relationships to form, and to support a social interaction without some kind of shared co-authored works. The increasing audience of game or socialware implementations, like Second Life [15] and Active Worlds AWEDU [16], point out to a more game-like solution applied to virtual environments with more interactive contents. Play ethic (methods) applied to work turn activities that employ computers a more comfortable experience. This is commonly referred to game-like interface. Socialware implementations can have a 3D representation aiming to display more realistic (virtual) worlds to its users. An alternative association from social learning environments captive more attention from students while can focus on collaboration for education. Virtual environments that employ game-like interfaces in their design with purposes other than entertainment are referred as serious game.

III. Computer Supported Labs

In this section some of the lab technologies commonly used in education will be discussed.

A. Remote and Virtual Labs

A key aspect of electronic/electrical engineering education is the application and evaluation of theory to real circuits where students apply stimulus to circuits via instrumentation and monitor the outputs [17]. Web accessible laboratories with remote experiments have become an attractive economical solution for the increasing number of students [18].

While the remote access of real laboratory equipment has several advantages, there are also some issues to be considered for teaching control and automation concepts: i. the number of students / students groups working simultaneously is equal to the number of physical experiments available; ii. real systems with a slow dynamic lead to long waiting times; iii. interlocking systems have to be carefully developed in order to avoid damage of components via improper actuation (security). Such drawbacks can be overcome by employing simulated components. Simulations, although sometimes unrealistic, have some intrinsic characteristics that can be explored in different learning scenarios. One of the main advantages of using executable simulation models is that they can be easily replicated. Students can use multiple copies (replicas) of the same simulation simultaneously. Another advantage of using simulation is that students can speed up slow dynamics systems for quick visualization. Safety concerns involving simulation variables limits are not as important as in real experiments since the models cannot be damaged. Web accessible simulations used as experiments are commonly referred as virtual labs.

Our experience has shown that the availability of remote experiments is not a sufficient condition to ensure success in the learning process of control and automation engineers. Remote lab experiments offered as *stand-alone* settings, without connection to adequate learning material (explaining the topics that are to be learned in the experiment), usually lead students to a *trial and error strategy*, which has a lower learning impact than originally expected. Moreover, remote labs are available 24/7 for a large audience of students increasing the demand in the number of faculty members and tutors that are necessary to provide on-line guidance to students.

B. Mixed Reality Labs

By analyzing the pros and cons of real vs. simulated experiments, one can see that in some sense they are complementary so that a combination of both possibilities seems interesting. The interchangeable components strategy has been developed to allow the combination of both real and virtual components [19] supporting this way the definition of a variety of learning scenarios.

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 [20]. The information overlay is employed by remote collaborators to annotate the user's view, or may enhance face-to-face conversation producing shared interactive virtual models. In this way, mixed reality techniques can produce a shared sense of presence and reality [21]. Thus, mixed reality approaches are ideal for multi-user collaborative lab and work applications [20].

IV. Related Works

In order to pinpoint the present work in the scientific community a wide range of state of the art research was conducted and the most prominent works of this study are displayed.

Virtual laboratories were the first implementations after simple Web tutorials to really add value to education, especially in the technical field where practice is necessary. Among the scientific community there is a wide range of results and VLabs available. The VCLab [22] is good example of virtual laboratoriess used for education that employ merely simulations to illustrate practical situations. Mostly these simulation use common software tools like: MatLab [23], LabView [24] or similars to model and simulate the behavior of virtual experiments that mimic real practice or didactic scenarios.

The Automatic Control Telelab (ACT) proposed by [25] offers a remote lab facility, i.e., real experiments made accessible through the Web. This particular implementation supports not only controller parameterizations, but also MatLab Simulink models to describe and characterize the controller logic. This interesting approach is very useful in the experiment configuration. Thus, students can design their own experiment controller in a much more flexible way.

The Solar Energy e-Learning Lab from [26] has a integrated learning system with several learning materials and "quizzes" to identify student understanding level. First, the student must pass several theory tests, so that the system grants remote experimentation access to a real solar energy plant facility. Despite these qualities the system does not offer experiment feedback.

Collaboratories [27] are a well known association of collaborative tools with remote laboratories (experiments). This solution brings up not only collaboration support but promotes that several students interact in a single experiment.

Another excellent example of flexible experiments configuration is the deriveSERVER system proposed by [27]. Unlike the others, this employs mixed reality techniques, using hyper-bonds [28] as bidirectional connectors, and is integrated in the VLE with collaborative and distributed learning methods. Another interesting approach employed in CSCEs is the use of CAVEs associated to mixed reality. In [29] such approach is described where CAVE canvases (projections) links collaborators in the same *environment* (CAVE). The common virtual workbench and the real workbench (via video projection) are available via Web and visible at an enlarged screen or are beamed at canvases.

Another approach presented by the project SLOODLE [15] describes the merge of 3D world representation of Second Life with MOODLE to mirror Web-based classrooms with in-world learning spaces and interactive objects. Compared to other electronic tools for distance communication (Computer Mediated Communication – CMC), the metaverse representation improve the sense of being there (in a classroom), rather than of being a disembodied observer, like most 2D virtual environments. This representation employs state of art technologies that support collaboration, creativity and sharing over the Web.

In [30] a virtual campus is created with several didactic materials, simulations and also an immersive interface to remote laboratories in the social 3D World hosted by Second Life. This is a particularly close solution to the forthcoming proposed architecture.

One distinct serious game implementation for medical training is the JDoc [31] that adds great motivational characteristics instructional systems.

V. Proposed Architecture

Computer Supported Collaborative Environments (CSCEs) can be implemented in a way which is suitable for work, training as well as for learning applications. The former would allow a shared workspace, the later a shared learnspace, both with floating boarders. Thus, the same technical function can be applied with more productive or more didactical aims.

Including a social serious game interface with a 3D world representation gives the environment a skin or metaverse as in [32] previously cited. Simulations of industrial plants and engineering concepts illustration examples within social 3D interfaces are being deployed currently in SL metaverse and these works indicate the future trend of CSCEs [30].

Educational tools to enhance system awareness of student's learning status, as proposed by [33], near CSCE's to automatic learning systems capable of autonomous or automatic tutoring (sometimes also referred as ITS – intelligent tutoring systems). Environment's collaboration awareness demonstrates also automatic capabilities associated to CMC. Following this trend, ideas to implement awareness agents (from Multi-Agent Systems – MAS) developed in Java (JADE - Java Agent Development Environment [34]) that monitor and capture students interactions with the MOODLE [35, 36] or the metaverse can be employed in the CSCE.

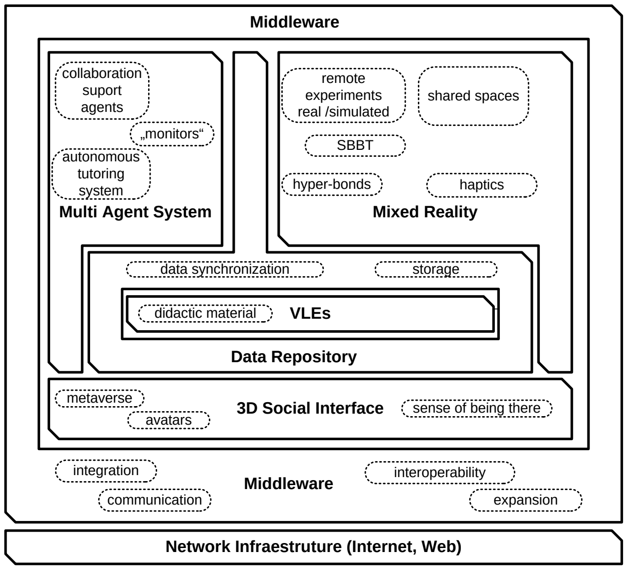

Figure 1. CSCE reference model architecture.

Within this context, an CSCE architecture can be envisioned with serious game social interactive interface, 3D representation and with as much autonomous support as possible is under development and subject of this work. Each of the underlying technology or concept of CSCE is depicted in the diagram of Fig. 1 as modules. Modularization has the purpose to bring distribution, expansion and reusability to the CSCE's architecture design. Each illustrated module is responsible for one or more related characteristic(s):

i. VLEs: central educational tool;
ii. 3D social metaverse: interface;
iii. Awareness Agents (MAS), Collaboration support and Tutoring systems: intelligence and adaptability;
iv. Mixed reality, Remote experiments and Shared workspaces: collaboration tools and flexibility;
v. Middleware: communication, integration, interoperability.

The network infrastructure is perhaps the most obvious solution to spread the CSCE and although also depicted but not a module. How to get all this functionalities/modules of the CSCE to work together is a very complex task addressed to the middleware.

Collaborative environments are based on distributed technologies to facilitate teamwork between geographically dispersed groups. More concretely, the design of a good distributed architecture can be the ground of any kind of application. Interoperability must be carried out in order to provide new services to end users with total integration into the platform.

The simplest way to grant interoperability is to employ common, simple, widely spread and standard technologies. The use of Web services like, SOA and/or XML-RPC is in this case strongly recommended.

The system awareness of gestures or references from remote teachers/students within CSCEs increase CMC (Computer Mediated Communication) to levels compared to face-to-face communication in shared workspaces [37]. The inter reference awareness of a CSCE allows a participant to refer to a set of objects of a collaborative environment and that reference be understood by other physical dispersed participants virtually present in the environment.

VI. Case Studies

Several case studies were proposed with the goal to achieve one primary prototype. The prototype as envisioned in Fig. 2 was developed. To illustrate each functionality the prototype was dismembered into four related case studies of minor complexity, but each one with a specific goal and concept related to the primary prototype.

Among the state of art of CSCE involved technologies and concepts several were hardly studied. The use of MOODLE as standard VLE was previously advocated in [19]. OpenSim [38], Open Simulator, one Second Life closely related free and open implementation was chosen as 3D social interface. Similar implementations were also tested and studied, like Active Worlds, Wonderland. Although Wonderland also offer free open source code and Java advantages, this implementation demands more computational power. OpenSim on the other side requires low computational power (server), can be freely explored, has a large developer community and runs in several platforms.

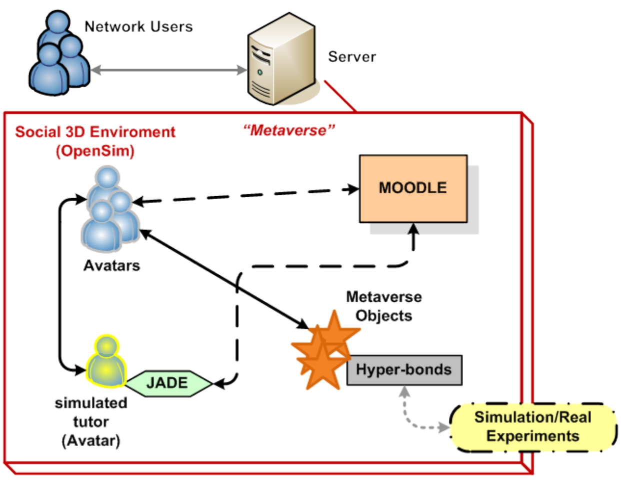

Figure 2. CSCE architecture prototype.

The first case study, an implementation of MAS for monitoring experiment bookings, was developed using normal booking system developed previously using PHP linked with MySQL database associated with the JADE framework for development of MAS. JADE is based on Java and uses standardized FIPA agents using common Java RMI for agent intercommunication. This implementation has proved the efficiency of MAS associations with VLEs for common but also for complex tasks. This illustrates the interoperability of MAS with database based systems, like VLEs and booking systems.

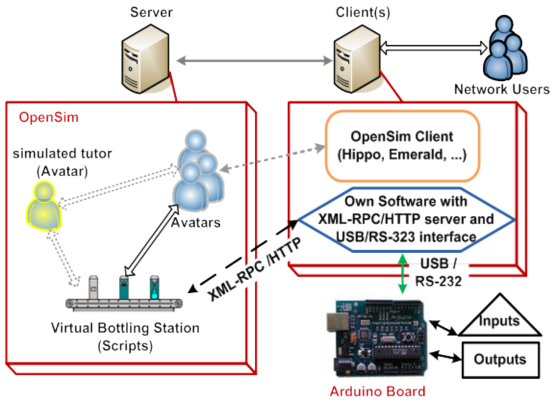

Figure 3. MR bottling system communication schema.

The next developed case study uses OpenSim as mixed reality social environment. Associations with metaverse objects with external real and simulated equipments where successfully tested using the open library for metaverse development, called LibOpenMetaverse (lomv), designed in C# based on .Net and XML-RPC technologies. The Fig. 3 illustrates the mixed reality communication scheme when using the Arduino [39] development board (real hardware) to control the bottling station (virtual, located in the metaverse). Informations like sensor readings (virtual) are send to the controller (real), via USB/RS-232 and XML-RPC gateway software, and this according to the readings sends messages to the actuators (virtual) automatizing the bottling production system (virtual) (see Fig. 3). The proposed implementation with the software and hardware I/Os connection is depicted in Fig. 4.

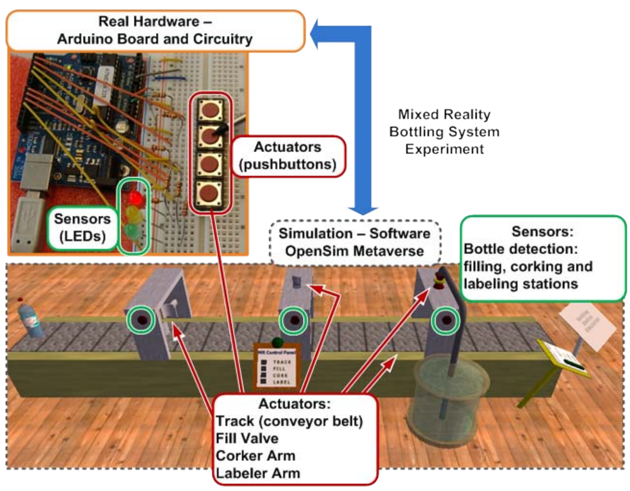

Figure 4. Mixed Reality bottling system experiment.

The last case study uses the LibOpenMetaverse to create automated bots. These bots act autonomously according to a list of predefined instructions responding to metaverse (objects and other avatars) interactions (follow, react, write on chat) and chat commands (see Fig. 5). This is a simple implementation of a basic ITS (Intelligent Tutoring System) to give students feedback to questions and system usage information.

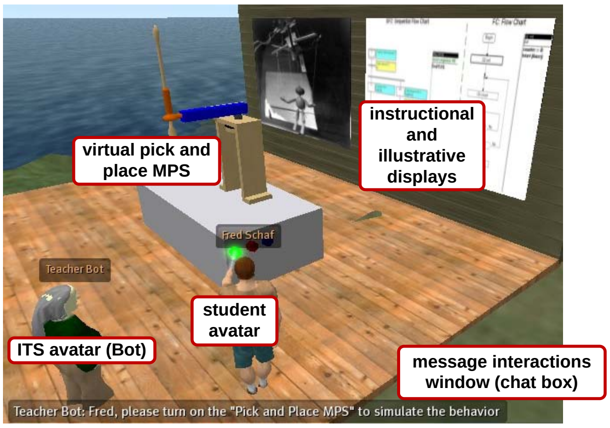

Figure 5. Bots as autonomous tutors.

The Fig. 6 displays the metaverse created to host the results of case study and is the testing ground of the developed prototype. This metaverse is result of a partnership from a Brazilian and a German university. Some other results as the display of multimedia learning materials, Weblinks, virtual and mixed reality experiments, 3D interface to remote experiments, etc within the metaverse were also developed.

Figure 6. Proposed metaverse snapshots.

VII. Future Works

As of any prototype – validation of a proposed architecture – in the learning field this implementation still needs to confirm his concepts and expectations in classes. This is the actual final test of this work that has the purpose to enhance education in automation systems.

The ITS will also further developed to achieve more concrete interaction range and not just react to simple *signals*. A future study will address efforts to this subject area.

Naturally more learning materials, virtual/real and mixed reality experiments will integrate the metaverse that as mentioned before will be the breeding grounds for new learning assets.

VIII. Conclusions

Although many studies do not prove the efficiency or the educational success of remote/simulated/hybrid labs as well as CSCEs, the lack of a better methodology, or even the lack of support by the educational institutions seem not to reject the scientific collaboration of this research field. Maybe the new outcomes of this technology will be better understood and employed with effort of today's studies.

The prototype is not fully finished and in the future will be evaluated by our students using usability ratings that focus on the mechanics of collaboration. Of course there is a trade-off in having geographically distributed applications and the higher communication times that are required. However, there are several benefits in exchange for these problems and also technologies are still in development to overcome delays in the transport of information. Among the advantages, the possibility to collaborate with more and previously hard reachable experts and resources.

In the educational sphere, researches clearly indicates that in many (not all) cases students learn more effectively through collaborative interaction with others. This motivates to prepare remote labs for collaborative learning (called collaboratories) and to use them in distributed teaching scenarios with simulation tools, hands-on laboratories and practical workshops. As a whole, there is a necessity to improve the usability of collaborative remote laboratory tools, because otherwise learners may quickly get frustrated and stop working with it.

References

[1] Williams, S. and Roberts, T.S. “Computer-Supported Collaborative Learning: Strengths and weaknesses”, *Computers in Education*, vol.1, pp. 328 – 331, 2002.

[2] Watson, K. “Utilization of Active and Cooperative Learning in EE courses: Three Classes and the Results”, *Proceedings of the Conference Frontiers in Education*, vol. 2, pp. 3c2.1 – 3c2.6, 1995.

[3] Smith, K.A. “The Craft of Teaching Cooperative Learning: an Active Learning Strategy”, *Proceedings of the Conference Frontiers in Education*, pp. 188 – 193, 1989.

[4] Auer, M. et al. “Distributed Virtual and Remote Labs in Engineering”, *Proceedings of the IEEE International Conference on Industrial Technology (ICIT)*, vol. 2, pp. 1208 – 1213, 2003.

[5] Faltin, N. *et al*. “Distributed Team-Learning in an Internet-Assisted Laboratory”, *Proceedings International Conference on Engineering Education*, Manchester, UK, 2002.

[6] Schaf, F. M. and Pereira, C. E., "Automation and Control Learning Environment with Mixed Reality Remote Experiments

Architecture", International Journal of Online Engineering, vol. 3, 2007.

[7] Ma, J. and Nickerson, J. V., "Hands-on, Simulated, and Remote Laboratories: a comparative literature review. ACM Computing Surveys, vol. 38(3), 2006.

[8] Grudin, J., "Why CSCW fail? problems in design and evaluation of organizational interfaces", in: Proceedings of the Second Conference on Computer Supported Cooperative Work, pp. 8- 93, 1988.

[9] Kaptelinin, V., "Computer Mediated Activity: functional organs in social and developmental contexts. *MIT Press*, 1996.

[10] Carroll, J. M., Neale, D. C., Isenhour, P. L., Rosson, M. B., and McCrickard, D. S., "Notification and Awareness: synchronizing task-oriented collaborative activity", *International Journal of Human-Computer Studies*, vol. 58(5), pp. 605-632, 2003.

[11] Stahl, G., Koschmann, T., and Suthers, D., "Computer-supported Collaborative Learning: An historical perspective", Cambridge University Press, 2006.

[12] Dougiamas, M. and Taylor, P., "MOODLE: Using learning communities to create an open source course management system", in: Proceedings of the World Conference on Educational Multimedia, Hypermedia and Telecommunications, pp. 171-178, 2003.

[13] Fuks, H., Raposo, A., Gerosa, M., Pimentel, M., Filippo, D., and Lucena, C., "Inter- and Iintrarelationships between Communication, Coordination and Cooperation in the Scope of the 3Cs Collaboration Model", in: Proceedings of the 12th International Conference on Computer Supported Cooperative Work in Design (CSCWD), pp. 246-252, 2008.

[14] Neale, D. C., Carroll, J. M., and Rosson, M. B., "Evaluating Computer-Supported Cooperative Work: models and frameworks", in: Proceedings of the 2004 ACM conference on Computer Supported Cooperative Work, pp. 112–121, 2004.

[15] Kemp, J. and Livingstone, D., "Putting a Second Life Metaverse Skin on Learning Management Systems", in: Proceedings of the Second Life Education Workshop at Second Life Community Convention, 2007.

[16] Corbit, M., "Building virtual worlds for informal science learning (SCICENTR and SCIFAIR) in the active worlds educational universe (AWEDU)", *MIT Press Journal*, vol. 11, pp. 55-67, 2002.

[17] Wolf, W. and Madsen, J., "Embedded Systems Education for the Future", *Proc. of the IEEE*, vol. 88(1), pp. 23–30, 2006.

[18] Cooper, M., "The Challenge of Practical Work in a eUniversity - real, virtual and remote experiments", in: Proceedings of the Information Society Technologies Conference, 2000.

[19] Schaf, F. M. and Pereira, C. E., "Integrating Mixed Reality Remote Experiments into Virtual Learning Environments using Interchangeable Components", *IEEE Transactions on Industrial Electronics*, vol. 56, pp. 4776–4783, 2009.

[20] Müller, D., Bruns, F.W., Erbe, H.-H., Robben, B., and Yoo, Y.-H., "Mixed Reality Learning Spaces for Collaborative Experimentation: a challenge for engineering education and training", *International Journal of Online Engineering (iJOE)*, vol. 3(4), 2007.

[21] Enlund, N., "Being Virtually There Reality and Presence in Mediated Learning", in: Proceedings of the 2001 International Conference on Telecommunications for Education and Training, vol. 3(4), pp. iv – ix, 2001.

[22] Schmid, C., "The Virtual Control Lab VCLab for Education on the Web", ACC'98, Philadelphia, pp. 1314-1318, 1998.

[23] Matlab, http://www.mathworks.com

[24] LabView, http://www.ni.com/labview

[25] Casini, M., Prattichizzo, D. and Vicino, A., "The Automatic Control Telelab: a web-based technology for distance learning", *IEEE Control Systems Magazine*, vol. 24, pp. 36 – 44, 2004.

[26] Kouzes, R. T., Myers, J. D., & Wulf, W. A., "Collaboratories: Doing science on the internet", *IEEE Computer*, 29(8), 40–46, 1996.

[27] Müller, D. and Ferreira, J. M.," MARVEL: A mixed-reality learning environment for vocational training in mechatronics", In: Proceedings of the technology enhanced learning international conference, pp. 65–72, 2005.

[28] Bruns, F. W., "Hyper-bonds—Distributed collaboration in mixed reality", *Annual Reviews in Control*, 29(1), 117–123, 2005.

[29] Schaf, F. M., Müller, D., Bruns, F. W., Pereira, C. E., Erbe, H. H., "Collaborative Learning and Engineering Workspaces", *Annual Reviews in Control*, v. 33, p. 246-252, 2009.

[30] Callaghan et al., "Intelligent User Support in Autonomous Remote Experimentation Environments", *IEEE Transactions on Industrial Electronics*, vol. 55(6), pp. 2355-2367, 2008.

[31] Sliney, A., Murphy, D., "JDoc: A Serious Game for Medical Learning", in: First International Conference on Advances in Computer-Human Interaction, pp.131-136, 2008.

[32] Hendaoui, A., Limayem, M., and Thompson, C. W., "3D Social Virtual Worlds: research issues and challenges", *IEEE Internet Computing Magazine*, vol. 12, pp. 88-92, 2008.

[33] Chastine, J. W., Zhu, Y., and Preston, J. A., "A framework for inter-referential awareness in collaborative environments", in: Proceedings of the International Conference on Collaborative Computing: Networking, Applications and Worksharing, 2006.

[34] JADE, http://jade.tilab.com

[35] Otsuka, J. L., "A Multi-agent Formative Assessment Support Model for Learning Management Systems", in: Proceedings of the 7th IEEE International Conference on Advanced Learning Technologies, 2007.

[36] Scutelnicu, A., Lin, F., Kinshuk, Liu, T., Graf, S., and Mc-Greal, R., "Integrating JADE Agents into MOODLE", in: Proceedings of the International Workshop on Intelligent and Adaptive Web-based Educational Systems, pp. 215–220, 2007.

[37] Gutwin, C. and Greenberg, S., "Workspace Awareness for Groupware", in: Conference on Human Factors in Computing Systems, 1996.

[38] OpenSim, http://opensimulator.org

[39] Arduino, http://www.arduino.cc

AUTHORS

F. M. Schaf is with the Universidade Federal do Rio Grande do Sul, Av. Av. Osvaldo Aranha, 103 CEP: 90035-190 - Porto Alegre, RS - Brasil (e-mail: frederico.schaf@ufrgs.br).

C. E. Pereira, is with the Universidade Federal do Rio Grande do Sul, Av. Av. Osvaldo Aranha, 103 CEP: 90035-190 - Porto Alegre, RS - Brasil (e-mail: cpereira@ece.ufrgs.br).

D. Müller is with the Universität Bremen, Enrique-Schmidt-Str. 7, 28359 Bremen, Germany (e-mail: mueller@artec.uni-bremen.de).

This work is partially financed by the Brazilian research agency CAPES.