This paper is structured as follows: section 2 discusses the evolution of educational labs, which was enabled by advanced IT technologies. Section 3 discusses issues in the integration of the labs into e-learning environments, presenting the main modules of such environments and discussing relevant related work presented in the literature. In Section 4 the GCAR e-learning system is presented. This system, developed by the authors, aims to be a collaborative immersive learning environment for control and automation engineering education. Sections 5 presents developed case studies and results obtained in the use in classroom. Finally, Section 6 draws conclusions and signals possibilities for future research work.

It is important to mention that due to its page limitation, this paper does not intend to be a thorough literature review on this fascinating area. There are some very good surveys on the topic and interested readers may refer to papers such as [8, 9], as well as recent special issues of scientific journals (for instance the special issues of IEEE Transactions on Industrial Electronics [10] and [11], or some specialized books [12, 13], or even two online international journals iJOE (Online Engineering) and iJET (Emerging Technologies in Learning).

II. HANDS-ON, SIMULATED, REMOTE, VIRTUAL, AND VIRTUAL WORLD LABS (AND BEYOND…)

As already discussed, laboratory-based courses are of critical relevance for engineering education and advances in IT and Internet have made available a large set of technologies that enable the construction of several different types of laboratories.

As pointed out by [9], two characteristics distinguish hands-on labs: (1) all the equipment required to perform the laboratory is physically set up; and (2) the students who perform the laboratory are physically present in the lab. Both characteristics have drawbacks: the high costs to install, operate, and maintain the real physical equipments that can only be used by a restricted number of students, both due to lab space limitations as well as due to the number of equipment available that can be simultaneously used.

In simulated labs (also called virtual or VLabs) the entire infrastructure required for laboratories is not real, but simulated on computers. Software tools such as MatLab, LabView, Modelica, etc. are used to model and simulate the behavior of experiments that mimic real practice or didactic scenarios. The significant increase in the processing power and reduced costs of personal computers have made multi-core, multiple GPU (Graphical Processor Units) available at very affordable prices even for universities in developing countries. These computers allow the simulation and graphical presentation of complex technical processes with a near real-time behavior. Simulation can be useful in reducing the amount of time that students have to spend on executing the experiments. For instance, slow experiments such as level control of a large tank that could take hours to run in a real setting, can be executed very quickly using simulation, leaving the students with more time available to analyze the control characteristics of the experiment, such as rise time, overshoot, etc). Additionally, as indicated by [14] "the students using a simulator are able to 'stop the world' and 'step outside' of the simulated process to review and understand it better".

There is a wide range of simulated labs described in the literature. The VCLab [15] is a good example of virtual laboratory used for education that employs merely simulations to illustrate practical situations. Dormido reports in [16] the use of a developed tool named EasyJava that offers the possibility to create simulated experiments from dynamic models from MatLab. In [17] the development of SimQuest is reported, which uses the guided learning discovery allied to simulations.

One of the main drawbacks of simulated labs is that they frequently rely on idealized models that do not fully correspond to real-life situations. The important learning experience of identifying the differences between theoretical models and real-life behavior may be missed in simulated labs [18].

The concept of "remote labs" is used when a remote access to hands-on labs is allowed. What makes them different from real labs is the distance between the experiment and the experimenters [9]. Remote labs are becoming very popular [19, 20, 21, 22]. They have the potential to provide affordable real experimental data through sharing experimental devices with a pool of schools [23, 24]. Also, a remote lab can extend the capability of a conventional laboratory. Along one dimension, its flexibility increases the number of times and places a student can perform experiments [25, 26]. Along another, its availability is extended to more students [2]. Additionally, comparative studies show that students are more motivated and willing to work in remote labs [2]. Some students even think remote labs are more effective than working with simulators [27]. Remote experiments to teaching and research are present in several different areas: digital process control [28, 29, 30], aerospace applications [28], PID control [31, 32], predictive control, embedded communication systems [15], and real-time video and voice applications [33], among others. There are also several projects on which different institutions join their efforts, so that a network of remote laboratories become available, such as LabNet [34], CyberLab [35], RwmLAB [36], DSP-based Remote Control Laboratory [37], DEEDS [38], NCS Laboratory [39], MARVEL [40], RExNET [41], iLabs [42] and others.

While, from an initial perspective, the concepts of hands-on, simulated, and remote labs seem to be very distinct and somewhat contradictory, a more careful analysis indicates some interesting commonalities. Particularly due to the need to ensure a safe operation of hands-on labs by students (given that students operate the devices locally, an improper handling of real equipment that could lead to dangerous situations, such as explosions, would also be potential dangerous to the students), most of the hands-on labs for control and automation education include safety systems, such as interlock devices, and includes some supervisory and automation systems. In several cases, students can only operate the real equipment via human-machine interfaces (HMIs) of supervisory systems, so that also in the case of hands-on labs the interactions are computer mediated. It is also not uncommon that such HMIs are located in control rooms, resembling what occurs in real control and automation applications that are isolated from the real devices.

This leads to the fact that all types of labs discussed so far (hands-on, simulated, and remote) are then mediated by computers, blurring the boundaries among them and making the "psychology of presence" to become more important than technology [9].

Additionally, considering the pros and cons of hands-on vs. simulated experiments, one can see that in some sense they are complementary so that a combination of both becomes interesting. Simulations, although sometimes unrealistic, have some intrinsic characteristics that can be explored in different learning scenarios. One of the main advantages of using simulated labs is that they can be easily replicated. Students can use multiple copies (replicas) of the same simulation simultaneously. As already mentioned, 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 simulated models cannot cause injuries.

This complementarity was the motivation to the creation of the interchangeable components strategy that has been developed to allow the combination of both real and virtual components in control and automation education [31]. The basic idea is that given that students usually have to use HMIs to access both real and simulated labs, and also due to the fact that usually these interfaces only provide visual and hearing feedback, they can be unable to differentiate if they are interacting with a real or a simulated device or technical plant. As described in [43], simulated components can be combined to real equipment to illustrate different learning situations (see Fig. 1). For instance, a simulated plant can be used to evaluate possible effects of control actuation, avoiding damages to physical equipments that would occur in real plants in case of errors in the control algorithms. On the contrary, a simulated controller interacting with a real plant can be interesting in the sense that internal controller's variables and behavior can be better understood. The use of a simulated plant together with a simulated control algorithm can be very useful in activities such as parameter tuning, taking the already mentioned possibility offered by simulated systems, to speed up the behavior of slow technical processes allowing a faster system identification.

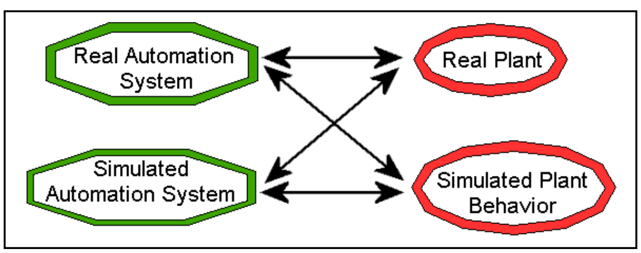

Figure 1. Interchangeable components strategy diagram

The idea proposed in [43] is more broad than the concept of virtual labs as defined in [44]: "Virtual laboratories represent distributed environments of simulation which are intended to perform the interactive simulation of a mathematical model of a real system", which basically means a remote accessible simulated lab. Regarding to this definition, it is here important to mention that definitions used in existing literature is not consistent and very often confusing. For instance, as identified by [9]: remote labs are called Web labs [45], virtual labs [46] or distributed learning labs [47] in different studies. And the concept of virtual lab used by [46] is different from the definition used by [44]. Table I summarizes the main characteristics of lab types that have been discussed so far, based on the use of simulated vs. real equipment as well as on a remote vs. local access. For a comprehensive comparative literature review on the discussion regarding pros and cons of hands-on, simulation, and remote labs readers are further referred to [9].

TABLE I. LABS CLASSIFICATION

ACCESS	*EQUIPMENT*	*LAB TYPE*
LOCAL	**Real**	**hands-on labs**
	Simulated	**simulated labs**
REMOTE	**Real**	**remote labs [3]**
	Simulated	**virtual labs [44]**
REMOTE AND/OR LOCAL	**real/simulated**	**interchangeable components [43]**

More recently, enabled by advances in areas such as computer graphics, mixed reality labs and virtual reality labs have been developed. Virtual reality is defined in [49] as "an experience in which a person is surrounded by a three dimensional computer-generated representation, and is able to move around in the virtual world and see it from different angles, to reach into it, grab it, and reshape it". [50] defined a mixed reality experience as "one where the user is placed in an interactive setting that is either real with virtual asset augmentation (augmented reality), or virtual with real-world augmentation (augmented virtuality)".

Based on the above definitions, "mixed or augmented reality labs" are defined as a live, direct or indirect, view of a hands-on lab whose physical devices are augmented by computer-generated sensory input such as sound, video, graphics or other information. Mixed reality interfaces can overlay graphics, video, and audio onto the real world by using devices such as tablets or head-mounted displays with location information, students can become information about the structure and behavior of the equipment they have to operate. Similarly, it is also possible to build digital mockups, in 2 or 3D perspectives, to graphically present the devices in simulated labs, leading to virtual reality labs on which the real world devices are replaced by their virtual models. An example of flexible experiments configuration is the deriveSERVER system proposed by [51]. It employs mixed reality techniques, using hyper-bonds [52] as bidirectional connectors to propose a fully mixed electro-pneumatics workbench.

Additionally to other approaches, the "sense of being there" concept can be widely explored through the immersion of the user into the practice environment, i.e., the user sees himself into the lab (feeling of immersion). Users exploring this virtual world (metaverse) are represented by their avatars, therefore a virtual presence is sensed by all users, especially during interactions. Compared to other electronic tools for remote communication, the metaverse representation improves the sense of being there (in a classroom), rather than of being a disembodied observer, like in most 2D virtual environments. Example of available software which can be used to the construction of virtual worlds labs are Second Life [53], Active Worlds AWEDU [54], Open Simulator [82] and Open Wonderland [91]. Given that with the use of those tools one can construct applications similar to games, but that are used for other applications than entertainment (here our focus is on their use for education purposes), they are name "serious games".

In this field there are several terms employed to the use of virtual worlds as hosting grounds to labs. The denomination "FutureLabs" is used in [55] to relate this topic using the ScienceSim project. Researchers from the University of Deusto in Spain [56] used Second Life to build their "WebLabs", where virtual objects are linked to a software tool designed to program a microbot (small size robot). After programming the robot, the user can watch a video of the behavior of the robot online in Second Life. They named their labs as "Second Labs". We prefer not to coin this term based on a specific technology or commercial tool, so we will use the term virtual world labs to designate them.

In the same direction, MIT researchers used the former virtual world implementation Wonderland (now Open Wonderland [91]) as breeding grounds to a variety of physics experiments from their iLabs [57]. These implementations benefited from the Java technology and their concept TEAL (Technology Enabled Active Learning) to enhance didactics in several realistic experiments in physics.

Most of the current implementations of virtual world labs, mixed reality, augmented reality and virtual reality labs rely only on computer mediated interfaces in their interactions with students. While those interfaces have an increasing capacity of generating very realistic visualizations, they usually only provide visual and hearing feedback to students, which can be enough for several applications, however, in some areas such as control and automation engineering education or medical training, other senses such as taste, smell, temperature, balance and acceleration are very important. This has motivated the development of what can be called "multiple senses Labs", which are virtual world labs with additional interfaces such as haptic, thermal, etc.

Systems with haptic interfaces are the most commonly adopted, given that being able to touch, feel, and manipulate objects, in addition of seeing and/or hearing them, provides a sense of immersion in the environment that is otherwise not possible. According to their input/output behavior, haptic interfaces can be characterized as impedance haptic, when position or velocity is sensed and the force is generated or as admittance haptic, if the force is sensed and the position or velocity is generated. Impedance-type architectures are most common, because they measure only position or velocity, while admittance-type architectures require measuring both position or velocity, and force [62]. Examples of experiments using haptic devices can be found in the areas of mechatronics [89], physics [59], industrial robots [60] and mobile agricultural equipment [61], among others

Remote handling with haptics allows users a better feeling for remote control and for collaboration in virtual environments. The former is a well studied problem known from remote robot control in astronautic or surgery applications. The latter has only recently found consideration with the widespread use of multi-user environments in games, entertainment, learning and tele-work.

Interactions can be made with one or more users on the same physical location and involve different senses. Directing Cave Automatic Virtual Environments (CAVEs) to engineering research areas, this environment can be employed as common engineering workspace used for solving a joined task, such as collaborative tele-design or tele-maintenance [63]. Flight simulators have shown good results in operation with single or more multiple users at the same physical location as well as in shared spaces [88]. Another point of view is the interaction of multiple users within a single virtual world without collaboration between them. In [58] such a scenario is explored for medical training, where multiple remote students can use a force-feedback experiment for needle insertion, without having to collaborate with each other, but with a sense of co-presence. Finally, another case is when multiple remote users want to interact with a virtual experiment and between them through force-feedback interfaces [89]. Such cooperation of users geographically dispersed in a shared virtual space, communicating with and sensing each other in a tangible way is a challenging task [62].

III. EMBEDDING LABS INTO E-LEARNING SYSTEMS

So far the focus of our discussion was in the labs evolution, enabled by advances in IT. However, experience has shown that the availability of those different types of labs is not a sufficient condition to ensure success in the learning process of control and automation engineering students. For instance, remote lab experiments that are not offered together with learning material explaining the topics that are to be learned usually lead students to the use of a "trial and error" strategy with a lower learning impact than it could be expected. Additionally, 24/7 available remote labs also require a 24/7 availability of teachers and tutors to provide online guidance. In order to alleviate these problems, remote experiments can be integrated with virtual learning environments (VLEs) [64, 31, 65, 40] that manage and provide learning materials before, during and after the experimentation. Based on our experience, such CSCEs for control and automation engineering education must include:

- shared workspace for educational media and theoretical material module - a virtual space to host general didactic material (commonly performed by VLEs);
- 3D social interface - responsible to give capabilities of metaverse to envisioned e-learning environments and host/manage virtual worlds for user immersion;

- user’s feedback and content adaptation - used to create automatic feedback or (learning) content adaptation;
- integration of labs or experiments with e-learning systems (VLEs);
- tutoring systems that take into account several user models and can automatically provide guidance (usually called intelligent tutoring systems [48]);
- support to team work and collaboration between students;
- augmented senses immersion – use of several levels of systems response, not only sight and hearing but also taste, temperature, balance, etc.;
- serious game concepts – the use of game-like solutions that capture attention and educate while entertain.

To the best of our knowledge there is no such implementation of a system available, which integrates all the mentioned features, but there are several interesting works that incorporate two or more of these characteristics and that will be discussed in the sequence.

The use of virtual reality as an educational tool has been proposed and discussed by several authors (see [92] for a good overview). Mixed reality interfaces allow the creation of shared workspaces that combine the advantages of both virtual environments and seamless collaboration with the real environment [66]. 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 [67]. Thus, mixed reality approaches are ideal for multi-user collaborative lab and work applications [66].

The collaborative learning skill is mostly associated with the social constructionist pedagogic line [71]. Collaboratories [72] 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.

Interactive VLEs are effective pedagogical resources, well suited for Web-based and distance education. Their interactivity encourages students to play a more active role in the e-learning process and provides realistic hands-on experience [68]. Moreover, VLEs are widely used for science teaching in areas such as Engineering, Physics, Mathematics or Biology since they provide everyone with public Websites to do practical experimentation from anywhere [9]. Nevertheless, the majority of the VLEs added in Web-learning environments are designed to be used individually, and they do not allow workgroup or collaboration among students and teachers [69]. The integration of VLEs inside collaborative learning environments can be seen in eMersion [70]. This Web-based platform contains a series of VLEs whereby students can experiment and share results among other students or with teachers [68].

In this merge from Web based VLEs and Virtual Worlds, [85] presents an approach called SLOODLE project that 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. The SLOODLE community collaborators developed an open-source free package that includes in-world scripts and a MOODLE module (collection of PHP files) providing direct link to VLE resources via HTTP and XML-RPC calls.

The Solar Energy e-Learning Lab from [64] has a integrated learning system (MOODLE) with several learning materials and “quizzes” to identify student understanding level. First, the student must pass several theoretical tests, so that the system grants access to the remote experiment, i.e., to the real solar energy plant facility. [31] reports on a similar system for a PID tuning experiment. An experiment analysis also identifies possible problems in the PID tuning and automatically (autonomously) infer which learning material has to be reviewed by the students. In [65] another similar experiment using the electro pneumatic mixed reality workbench from [50]. In [63] an experiment is described on which CAVE canvases (projections) links collaborators into a single 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.

One distinct approach is the serious game implementation for medical training called JDoc [73] that adds great motivational characteristics to instructional systems. Realistic graphics and simulation of medical patients' disease symptoms for diagnose are used to train prior to residency stage (real first practice).

There are also several interesting works about the use of student models and intelligent tutoring systems in e-learning environments with embedded remote experimentation. [74] reports on the use of educational tools to enhance system awareness of student's learning status before experimenting in a robotics virtual lab. This information is collected via a questionnaire of basic robotics. The data then feeds a student model that also gathers information of student's background. [75] reports the use of agents to global software development collaboration through a simulator that enables collaboration between inexperienced students and software engineers. Agents (chatbots) are used to allow interaction between system and users from the teacher, student and server interfaces. [76] reports on a work that combines virtual labs with serious games features and intelligent tutoring to improve motivation, knowledge and understanding of students. For this, from the student interaction with the environment, one tutor module analyzes the result reached by the student and decides the level and the pedagogical action needed. Multi-agents systems are also used for formative assessment support [77, 78].

In the field of virtual world labs, [87] designed a virtual campus (named Magee Campus), hosted in Second Life, with several didactic materials, simulations and also an immersive interface to remote laboratories in the social 3D World. The experiments are mostly simulations linked and virtual objects, but there are also virtual objects (linked to HMI) representing the connection to real physical equipments providing the environment with virtual lab and remote lab facilities. There is an interesting experiment called giant computer, where the avatar virtually walks (explores) the inside structure of a computer with its components. The Magee Campus can be considered the closest implementation that includes most of the features previously mentioned, but with a focus to computer science education. In the next section, a similar system is presented, which was developed by the authors and is focused for control and automation engineering education.

IV. GCAR E-LEARNING SYSTEMS

Our experience in applying remote experiments for control and automation started with the construction of a remote laboratory using a Foundation Fieldbus pilot plant [79]. With that system, students were able to learn PID tuning control techniques and industrial communication protocols by working with hypertext-based learning material and by remotely accessing the pilot plant in order to perform experiments on which they could put in practice the theoretical concepts learned in classroom. In order to organize the remote access to the remote plant, a tool has been developed, which was responsible for (i) validating users' access, (ii) scheduling appointments for students to run the experiments, (iii) controlling experiment scheduling, (iv) tracking data related to students' activities as well as (v) bring the experiment to a well defined initial state before experiments start.

Experiences in using the Foundation Fieldbus pilot plant showed that due to the fact that the learning material was "loosely coupled" with the remote experiment, students were not able to identify which topics to review in case they could not get the proposed experiments adequately done and frequently use a "trial and error" approach until they could get the work done. Additionally, it was not uncommon that students delayed the execution of the remote lab exercises to the last days before the deadline defined by teachers, leading to congestions in the access to the plant (given that there was one physical plant to could not be simultaneously accessed by several students).

In order to overcome those drawbacks, a system called GCAR-EAD [80] was developed, providing support to remote experimentation and mixed reality. It was integrated with a virtual learning environment - VLE (in this case MOODLE), included several learning materials, remote mixed reality experiments, interchangeable components strategy [31], experiment analysis and a some basic student guidance tools. The proposed architecture included five main modules: learning (didactic) material manager, student guidance system (or student guide), experiment booking, experiment analysis (or experiment analyzer) and experiment manager/interface. Each of these modules was responsible for controlling a specific functionality of the GCAR-EAD. The system is still employed in several control and automation engineering classes at UFRGS and results have been very positive, as will be presented later.

Despite of the very good results achieved, some possibilities to enhance the GCAR-EAD tool were identified: there was a need for tools to support students collaboration (synchronous interaction), to allow them to exchange ideas about possible solutions to the given problems. Also the need to include some support to the execution of task by students teams and not only by single users was identified. This "new" challenge was addressed by the development of second version of the GCAR-EAD called GCAR-3DAutoSysLab, in which the interface was "socialized" and integrated with virtual world labs.

In order to develop a feasible implementation for a virtual world e-learning environment addressed to control and automation engineering, the 3DAutoSysLab prototype was developed, in which: a metaverse (virtual world meta universe) is used as social collaborative interface; experiments with interchangeable components are linked to virtual objects; learning objects are displayed as interactive medias; and guiding/feedback are supported via an autonomous tutoring system based on user's interaction data mining.

The 3DAutoSysLab follows an architecture model for CSCEs based on modularity and interoperability among different functionalities and tools (see for instance [81] or [93]). The proposed architecture includes the characteristics cited in Section III as optimal for CSCEs for engineering and is depicted in Fig. 2.

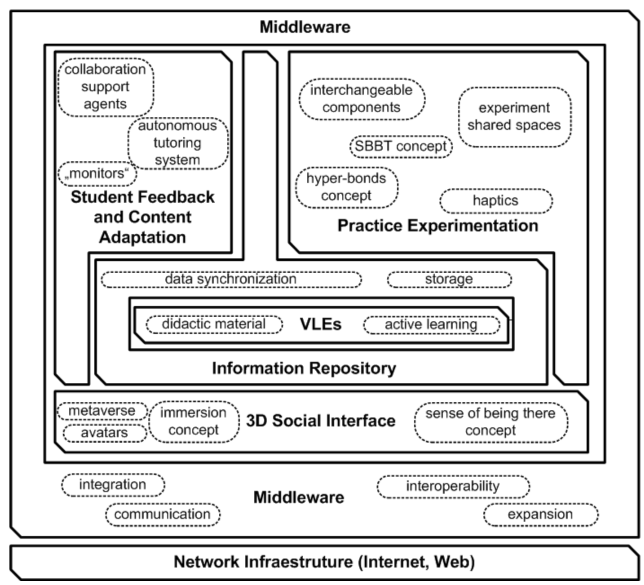

Figure 2. 3DAutoSysLab architecture

The first version of the GCAR-3DAutoSysLab (see Fig. 3) was deployed using MOODLE as VLE and OpenSimulator (OpenSim) [82], a free open-source project very similar to Second Life, as 3D social interface. The remote practice module includes both the experiments that were originally developed for the GCAR-EAD tool (and that were inserted into the virtual world) as well as some new virtual world experiments. These experiments will be summarized in the next section. Within the student feedback and content adaptation module, a preliminary version of an agent-based tutoring system and user feedback employing the JADE framework [83] was developed. These agents monitor and gather information from users that interact in the environment (data mining techniques) to adapt and infer learning material. All data is stored on the information repository implemented using a MySQL [84] database. The middleware is implemented using several communication tools and specifically designed software for interconnecting the different modules using XML-RPC, database communication support, SLOODLE [85] package (metaverse scripts), and others.

Figure 3. 3D AutoSysLab snapshots

3DAutoSysLab allows students to browse the learning material using the VLE MOODLE inside the virtual world and provides a social interface frontend designed to allow the sense of being there concept. Fig. 4 displays a snapshot of several users' interaction around a specific theme. Detailed information on the 3DAutoSysLab can be obtained in [81] as well as in the project Website [86].

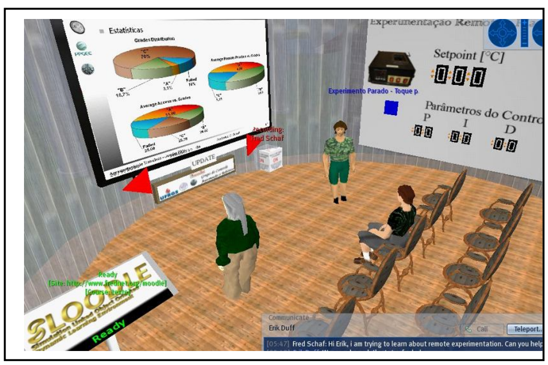

Figure 4. User interaction snapshot at 3D AutoSysLab

V. CASE STUDIES AND RESULTS FROM USE IN CLASSROOM

Several educational case studies have been developed (see [79, 43]) including a Foundation Fieldbus Pilot Plant, Temperature Control using industrial Controllers and a Thermal Plant, Mixed Reality Bottling Plant, among others. Over the last years, these experiments have been successfully used in undergrad and graduated courses on: Systems and Signals; Control System Design; Industrial Automation; Discrete Time Control, etc. The obtained results are very positive. In particular, student's motivation has significantly increased when using remote labs embedded into VLEs and blended learning strategies [80]. The use of the tool has been evaluated as "good" or "excellent" by more than 85% of the students. Analysis of CSCE logged data shows that while some students access the remote experiments very late at night, others prefer to work early in the morning and such 24/7 availability of the experiments is positively assessed by the students. The use of the tool has also very significantly impacted the students' performance. As depicted in Fig. 5 a steady decrease is observed in the students' failure rate over the last 8 semesters in which the tool has been adopted in the lecture "Control Systems" (offered to undergraduate students of the 7th or 8th semesters of the Electrical Engineering and Control and Automation Engineering courses).

Fig. 6 displays the mixed reality bottling system plant, that has been used in several lectures, such as: (i) in teaching PLC programming with the IEC 61131-3 standardized programming languages for automation; and (ii) in the development of micro-controller based sensor/actuator interfaces (for instance, Fig. 6 shows a real physical Arduino micro-controller board interfaced to the virtual plant).

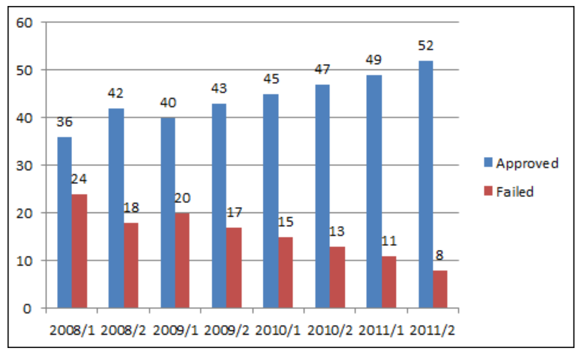

Figure 5. Approved/Failure Rates

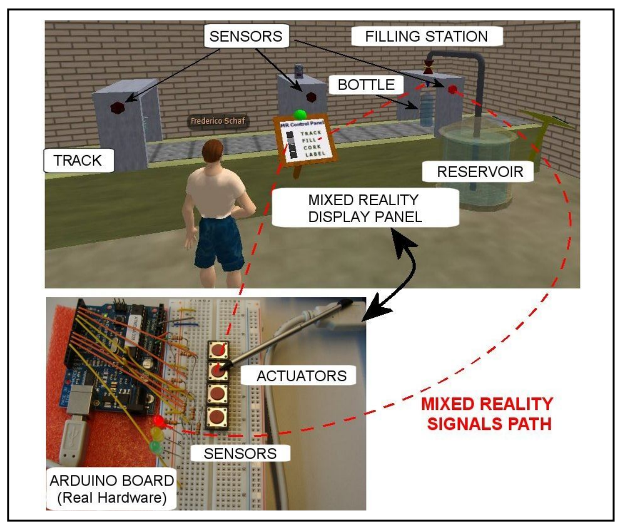

Figure 6. Mixed reality bottling plant

A particularly noteworthy result with the use of the tool was obtained in the class "Introduction to Control and

Automation Engineering”, which is offered to freshmen students, most of them between 17 and 19 years old. This course was created as a trial to reduce the drop-off number of engineering students, mainly in the first years of their courses, a phase on which their curricula is full with math and physics disciplines (which unfortunately are usually taught out of a context and do not show students possible application of the theory). The course includes some very basic micro-controller programming lectures and a final project work where the students have to develop a digital temperature control program. This project had to be tested using a remote lab, in which students had to upload their control programs to a microcontroller board interfaced to a didactic thermal plant, all remotely available. Students’ performance exceed by far the teachers’ original expectation, since not only they were able to meet all learning objectives, but even created additional requirements that make the proposed tasks even more complex. This confirmed our expectation that for younger generations the use of virtual worlds and computer mediated systems is a very natural process, so that they become very motivated and require little guidance to use the system.

VI. CONCLUSIONS

The purpose of this paper was to present an overview on the evolution of lab experiments for control and automation engineering education. Advances in IT technology have made possible the construction of virtual reality plants, which offers several new possibilities for engineering education. The paper has also discussed the importance of integrating such educational labs into e-learning systems and CSCEs for engineering education, in order to foster student collaboration and help students to establish connections between observations made while running the lab experiments and the theoretical concepts that explain the observed phenomena.

Based on the very positive results we have obtained over the last years with the development of such tools, we truly believe that they can make an effective contribution in motivating the students and in promoting effective learning.

Regarding automation engineering education, an interesting aspect is that such CSCEs benefits from the same IT technologies and concepts that are being adopted in the development of modern automation systems and that have to be taught to students. So, by using these environments students are also getting acquainted with technologies they will find in real industrial automation systems. And this trend will probably continue, given that concepts such as cloud computing, self-adaptive / self-evolvable systems, whose application to control and automation systems are a current research topic, can also be adopted to improve educational environments.

There is certainly a lot more of work needed until mature CSCEs for control and automation engineering education become widely available and in particular an integration of results from different research areas is required. This opens the possibility of multidisciplinary collaboration between educators and researchers from different institutions around the world. Hopefully all these efforts will allow us to motivate more young people to become engineers, and will help us to educate them to become ethic engineers, capable of designing innovative products and sustainable processes, using materials and energy for the benefit of mankind.

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