Laboratory Experimentation for Supporting Collaborative Working in Engineering Education over the Internet

S. Odeh and E. Abdelghani

Abstract—Collaborative working environments for distance education can be considered as a more generic form of contemporary remote labs. At present, the majority of existing real laboratories are not constructed to allow the involved participants to collaborate in real time. To make this revolutionary learning environment possible we must allow the different users to carry out an experiment simultaneously. In recent times, multi-user environments are successfully applied in many applications such as air traffic control systems, team-oriented military systems, chat-text tools, multi-player games etc. Thus, understanding the ideas and techniques behind these systems could be of great importance in the contribution of ideas to our e-learning environment for collaborative working. In this investigation, collaborative working environments from theoretical and practical perspectives are considered in order to build an effective collaborative real laboratory, which allows two students or more to conduct remote experiments at the same time as a team. In order to achieve this goal, we have implemented distributed system architecture, enabling students to obtain an automated help by either a human tutor or a rule-based e-tutor.

Keywords—Collaboration environment, e-tutor, multi-user environments, socio-technical system.

I. INTRODUCTION

IN the laboratory, instruments and equipment are inadequate when compared to the increasing number of students; however, it is very expensive to provide laboratory equipments to meet the increase in the number of students [1]. Moreover, many universities nowadays offer off-campus and distance learning programs such that the laboratory equipments or instruments are geographically located away from the student. The need to increase a collaborative learning in engineering education by means of delivering experimental data to people in different parts of the world has become a priority among students. Methods such as email do provide such a facility but they lack the ability to provide this data in a real time environment. Therefore, it is necessary to probe another approaches such as chat tools to provide data in a real time.

Unfortunately, there are many problems that still exist in remote experiments of engineering studies, such as not finding the proper assistance while performing an experiment, distracting students working on an experiment because of the lack of a proper feedback from other students, and inequality in task division between them. Therefore, the students will lose motivation and the experiment could fail, leading to ineffective learning.

Building distributed systems for enabling remote laboratory experimentation, which supports collaborative working in engineering education over the internet, enforces researchers to understand and to consider collaboration environments from both theoretical and practical perspectives. A collaborative real laboratory is effective if it allows two students or more to conduct remote experiments at the same time as a team. In order to achieve this goal, we have implemented distributed system architecture, enabling students to obtain an automated help by either a human tutor or a rule-based e-tutor. This system is organized into subsystems and components that allow the end-users (tutor and students) to interact with the system through a web-based user-interface, through which they carry out their tasks. However, this architecture has been built around an existing laboratory components and equipments in a general university/ engineering college. The architecture applied to this system follows the simplest client-server architecture, where an application is organized as a server and a set of clients. Making it possible to students to obtain an automated help by either a human tutor or a rule-based e-tutor for the purpose of student support in remote experiment environments, we had to facilitate synchronous interaction between students and tutor achieved by chat tool. Effective collaboration between students is obtained by using color coding to differentiate their contributions. A GUI facilitates the remote control and access of various instruments and experiment setups.

We will describe in-depth an architecture based on dot net technologies to support the software development process of web-based collaborative working environment, in addition to an interactive graphical user-interface (GUI) environment, through which it is possible to control and access of various instruments and experiment setups remotely. If we intend to design a user-interface ergonomically [2], we must differentiate between the sciences of perception- and cognition-ergonomics [3]. In particular, the cognition-ergonomics is related to the cognitive elements: reasoning, memory and knowledge [4]. The cognition-ergonomics

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comprehends a variety of design aspects such as the human memory storage, attention allocation, abstraction level, and information form including serial or parallel presentation; whereas the perception ergonomics is concerned with designing aspects such as color, shape form, dimension, allocation, highlighting etc. The web-based interface, which is realized as an integrated desktop, includes windows for displaying the experiment, a chat tool, a window for active users, and a dialog frame for session control.

We will see how we have implemented an e-collaborative environment for remote experimentation supplemented by a rule-based e-tutor based on Microsoft Visual Basic 2005 dot net framework [5] that gives support in order to facilitate the implementation of the web-based collaborative working. It is required to design an experiment set-up and to write software control code for interfacing it with both a lab server and the internet. It is to note that the detailed description of the implementation with its complete code listing is to be found in Abdelghani [6]. Making the web interface browser as a user-centered mediator between users and application, it was necessary to program controls to interface our experiment with the lab server and the internet. The laboratory experiment set-up is attached to a server, which provides the web interface to the remote clients. Multiple clients are able to get connected through remote login into the system [7].

II. e-Collaboration

As people often work with others and with the increasing importance of computers in work and everyday lives, it is natural to expect computers to play an important role in facilitating collaborative working [8]. Electronic collaboration (e-Collaboration) is the computer mediated process of two or more (dislocated) people working together on a common purpose or goal, where the participants are committed and interdependent as well as work in a common context using shared resources, which is supported by (web-based) electronic tools [9], [10]. We can set the goals of any collaborative working as:

- Each group member brings knowledge to the group.
- The groups share knowledge between them.
- Each person can contribute ideas and desirable work to be combined into a final result.

In engineering education, concepts taught through lectures are often complemented by laboratory experimentation. Students can observe phenomena that are often difficult to explain by written material. It is worth mentioning that collaborative learning in engineering education is of great significance because of the following reasons:

- Students acquire various skills, such as the ability to work in teams and to achieve objectives in collaboration with others.
- Students learn to communicate with each other using technical expressions that are specific of their professional engineering domain.
- Students learn to integrate the know-how of others in order to accomplish a given work task.
- Students acquire remote collaboration skills, when the teamwork is carried out from several locations.

Interactive experimentation on real world improves the students' motivation and develops an engineering approach to solve realistic problems. A collaborative environment must allow the experimentation in a team, where the group is able to interact and to discuss the results of their work. The shared features for any system supporting collaborative working are:

- Communication between partners.
- Coordination (roles and task attribution).
- Production (the task itself).

III. Collaborative Learning: Definition, social and psychological aspects

Collaboration between learners can have a positive impact in a learning session only if learners can exchange knowledge efficiently. Discussions and advice given by a co-learner are good means to help a learner in knowledge acquisition. Web-based collaborative environments are a special category of e-learning tools that support a group of learners in achieving a common learning goal. In local laboratory experiment, students usually work together in groups of two or more. This learning paradigm is often called collaborative learning; it develops skills for problem-solving task in a team. The premise of collaborative learning is based upon consensus building through collaboration by group members. Members of the learning group will usually organize their activities themselves and decide upon the roles of the different members via consultation and negotiation. With the rapid expansion and availability of communication and information technologies, collaborative learning can also be done effectively in a remote environment at different places. Collaborative working environments bring together users, which are geographically distributed, but connected via a network [11].

Students in the computer lab were able to see each other and talk to each other. Each student uses a computer adjacent to his or her group members. Usually, face-to-face students first rearranged their chairs so they formed a circle with members of their group in order to utilize their time in discussing a specific problem. Thus, the process was similar to communicating with a group of individuals in a chat group in the same room such as the computer lab. In many aspects, the face-to-face chat samples the computer-based chat. For example, students go back to their computers and answer questions, working with their group via the specific system software. The students are able to talk with the members of their group, but enter all their answers into the computer [12].

Different social and psychological aspects deal with collaboration in learning processes [13], [14]:

- *Cognitive Learning:* Learning produces sustainable results when external information or the requirements of a task can be embedded in already existing cognitive structure. In other words, it must serve as confirmation, modification or contradiction of the learner's existing knowledge. It is to note that cognitive science is interdisciplinary that draws on many fields such as psychology, artificial intelligence, linguistics, and philosophy that are combined together to develop theories about human perception, thinking, and learning.
- *Motivation:* The learning process will be better accepted and will lead to sustainable knowledge when learning is

experienced as the result of one's own activity, not as a mere adaptation to other people's knowledge.

- *Social construction:* The construction of the three social elements: understanding, knowledge acquisition and production are mainly based on collaborative knowledge-sharing interaction with others.

IV.   LEARNER AND INSTRUCTOR INTERACTION

In traditional classroom environments, the immediate two-way interaction that takes place between learners and instructors allows for a very flexibility type of teaching. A classroom instructor can change the learning content and interaction immediately based on feedback from the class. For example, by initiating a new activity, starting an open discussion, or finding alternate ways of explaining or demonstrating an unknown concept to a learner who may be having difficulty in understanding.

In such settings, teaching can take many forms, can occur within or outside of a designated learning environment, and can be prescriptive or reactive, planned or constructed. The instructor can adapt materials to meet individual student needs; and flaws and deficiencies in both course design and the instructional materials used to support teaching can usually be compensated for during the face-to-face teacher-learner interaction in the classroom. The traditional classroom environment also supports a wide variety of instructional methods including, for example, discussions, brainstorming, collaborative learning, etc. that create a highly interactive and rich learning environment. In contrast, the use of electronic and other distance learning technologies requires a carefully planned approach to instructional development, as communication between learners and instructors. In most cases, the instructor and learners are working in isolation, communicating through any form of media [15].

Many of the instructional methods used in a traditional classroom environment are implemented with both verbal and nonverbal forms of communication that are difficult to replicate in the types of media commonly used for distance learning. The four types of communications and interactions that may occur in distance learning courses include [15]:

- *Learner-content interactions:* Used to obtain intellectual information being in the form of text, images, simulations, etc. from the instructional media.
- *Learner-instructor interactions:* Two-way dialog to motivate learning, clarify concepts, and provide feedback.
- *Learner-learner interactions:* Provides an exchange of information, ideas and dialog between students, with or without instructor involvement.
- *Learner-interface:* Used to access and participate in instruction and communicate with instructors and other learners. The type of interface - either a book design, an interactive computer program, or other interface - is dependent on the technologies and media used to deliver learning.

It is to note that good learner-interface interaction allows the learner to concentrate on the other three types of learning interactions. If poorly designed, the learner-interface interaction distracts the learner from accessing content and communicating with others.

V. LEARNING WITH INSTRUCTIONAL SUPPORT

Complex problem solving tasks without instructional support will often require too much from the students, leading to ineffective learning. The ability to engage in a two-way communication (instructor and learners) allows distance learners in facilitated courses to solve more complex learning problems. As long as students need instructions and help in solving scientific problems, the learning environment shall provide knowledge in this respect. Instructional support is an important element especially in problem-based learning settings; therefore, remote laboratories must provide support for students.

In remote laboratories, a tele-tutor communicates via synchronous or asynchronous communication tools with his/her students, resulting as a central role regarding instructional support. The web makes it possible to integrate synchronous and asynchronous technologies so that students can benefit from both. Such combination of technologies and the web site provide a richer basis for collaborative course. However, technologies choices must ensure that all students will be able to use these technologies, and that software is straightforward and pleasant to use [16].

A.   Asynchronous courses

In courses that are delivered asynchronously, each learner can make use of the communications medium at the most convenient time and place. As a result, these courses are available to others who have difficulty scheduling attendance in traditional classroom environments. In addition, asynchronous classes can be easily made available to a collaborative learning of learners who can share information and experiences with one another without regard to geographic boundaries or time limitations. In the simplest configurations, asynchronous courses can make use of extremely communications media such as e-mail [15].

Collaboration in asynchronous interactions is not convenient for some instructors and learners. As we know, asynchronous communications are largely text-based, which can limit the effectiveness of discussions delivered through this medium. Students who are not native speakers of the language used for course delivery face special difficulties, in addition to cultural and language barriers that easily lead to miscommunication and misunderstanding in text-based communications [15]. Discussions in a text-based medium can be difficult, and collaboration in such a discussion can take a lot of time for the learners. The delays in response in asynchronous classes often cause students to become distracted with other responsibilities rather than remaining focused on class participation, so the time required for the learner to respond to individual learner questions and problems is much greater than the time typically spent by teachers in traditional classroom settings [15], [17].

B.   Synchronous courses

Synchronous courses that employ two-way video or audio technologies can allow instructors and learners to collaborate in demonstration and observation of practices for a variety of skills-based learning activities in a way that it would not be possible in other forms of distance learning due to the fact that teachers and learners can engage in nearly all traditional learning activities through voice, text, and video. In these instances, the online classroom can begin to seem more like a traditional classroom in many respects, and teachers can begin to employ many of the same approaches used to teach face-to-

face classes, as well as being able to respond to visual and verbal forms from students [15], [17].

VI. DISTRIBUTED SYSTEM ARCHITECTURE AND DESIGN FOR COLLABORATIVE INTERNET-BASED EXPERIMENTATION

A. Introduction

The architecture adopted in this investigation for modeling the distributed collaborative experimentation system follows the simplest client-server architecture, where an application is organized as a server and a set of clients [18]. Figure 1 illustrates a system architecture accommodated to the special needs of this system for establishing a collaborative working e-learning environment, which is not only supported by a human tutor, but by a rule-based e-tutor as well. Its architecture enables the different users such as students and tutors to utilize the following capabilities:

- Performing on real (physical) experiments remotely, whenever they want and anywhere they are.
- Collaborating by two students or more and attributing the tasks between them.
- Developing of a remote experiment and hardware facility based on an existing course structure and requirements to facilitate the collaborative work remote learning scenario.
- Interacting synchronously between students and tutor.
- Giving the opportunity to use an automated help at any time.

B. Hardware architecture

A general scheme of the system that has been designed using client-server architecture is shown in Figure 1. The remote users (collaborators) can login to the e-collaborative server using TCP/IP link over the Internet and can select and perform an experiment. At the server end, hardware setup of all laboratory instruments and experiments are attached to the server, instruments and devices are also connected with the programmable instruments through a PCI General Purpose Interface Bus (GPIB) card and GPIB cables [19]. An experimental board containing different components and electronic elements are connected to the parallel port [20] of the server to view real-time experimental setup.
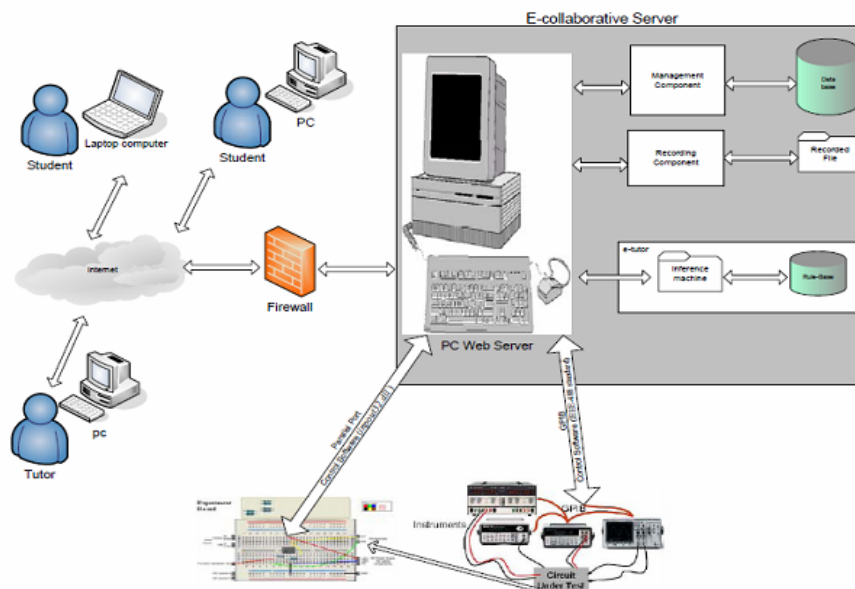
C. Software architecture and design

The software design for the e-collaborative environment for remote experimentation system focuses on a client-server type software model whose primary functionality is to interface the remote users (collaborators) with the server and controlling of the actual laboratory experiments/instruments. The GUI for the client side has been developed using Microsoft Visual Basic dot net (VB.NET). The server side controls the server process and it handles all the tasks of communication to and from the instruments using the instrument controller, a PCI GPIB card. Standard command for language library has been used in vb.net environment to send commands and to receive data from the instrument driver, which uses the GPIB IEEE 488.2 standard protocol in order to drive the instruments.

The clients' side controls the experiment interface by sending command to the parallel port for selecting different points related to the experiment board. The client side GUI allows the student to control various functions of the instruments associated with the experiment in real-time. For each instrument as well as experiment at the server end, corresponding GUI has been designed at the client end using vb.net control toolbox. After sending the students' manipulations on the experiment to the server, they will be checked by the e-tutor and then sent back to the client to be displayed on the client GUI. Some virtual and physical components of the distributed system will be roughly summarized in the following:

Fig. 1 Distributed system architecture of the e-collaborative environment for remote experimentation supplemented by a rule-based e-tutor

Session control window for remotly managing of experiment sessions: This window consists of buttons for creating a new user, logging-in and logging–out, session recording etc. The home page in our website implemented as "Login.aspx" [5] allows students to log in into their accounts and to carry out a distance experiment. Additionally, through the website, a new user can be registered.

Chat tool: Recently, more and more sites benefit from chat tools to help people socialize or sort out important issues. However, providing our system with a chat tool stimulates collaboration among students while executing an experiment. After starting the chat application, a web page based on "aspx" technology will be also started; after that, the student enters his/her true or alias name to be used in conversations between students. By means of the chat-text window (see Figure 2), a student can send a text message to a particular student or to all students at once. It also is possible for them to exchange messages using emoticons that are symbols or combination of symbols used to convey emotional content in written or message form.

Circuit-wiring electronic: In order to make it possible for students to manipulate the components and to wire a circuit remotely, a circuit-wiring device can be used (see Figure 3). The complexity of such a switching point increases with the number of circuit points provided. The user-interface of the experiment window, the virtual representation of the experiment is shown in Figure 4. For wiring the electronic elements together and connecting them with the instrumentations, a wiring and connecting tool realized as a pop-up menu can be used interactively. The pop-up menu offers various types of virtual wires and cables. The color and width properties are changeable by a pop-up menu. Every student can choose its own color and width for a line, distinguishing a student's work from others, showing the collaborative working between students, and equalizing the distribution of work between them.

On the client user-interface, virtual components as shown in Figure 4, are used to be connected with other electronic
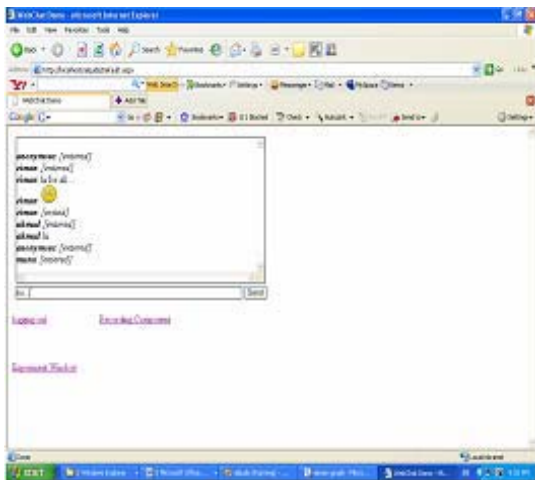

Fig. 2 Chat tool window

elements and instrumentations to achieve a certain circuit configuration. Each element or device on the bread board is represented graphically, and their terminals are highlighted by circles. When a student links two points to complete a close circle, he/she connects terminals that are marked by highlighted
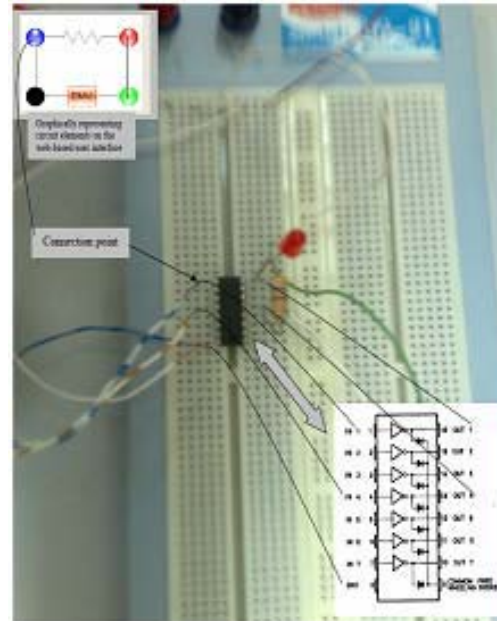

Fig. 3 Pin connections of dip 16 ULN2003 on the breadboard

circles as shown in Figure 4. While a student draws a line between two terminals, he/she has to position the mouse cursor on the specified circles of the terminals. The code for this functionality was written in vb.net, thereby the program stores the corresponding x y coordinates of that point in a text file, which will be then sent to the lab server.

Rule-based e-tutor: The e-tutor proves the validity of the connections in an interactive manner. That is, it marks the unaccepted connections with a different color, and informs interactively the students about their failures.

On the client side, once the student completes a circuit manipulation step, the configured connections will be stored in a text file for the purpose of sending them to the e-collaborative server. The way the e-tutor validates the wired electronic components on breadboard, works as follows:

1) For every experiment, the e-tutor knows the lengths between the circuit elements.

2) While a student connects the circuit terminals (highlighted circles) with each other, the client stores the lengths of the new drawn lines in a new text file.

3) If a student confirms the new changes on the circuit, the client sends the file containing the lengths to the laboratory server for comparison purposes, which is made by if-then rules.

4) The result of this comparison indicates the correctness of the manipulated connections. Accordingly, the lab server sends the client the new result to inform the student about his success or failure.

5) If the connections are valid, the server connects the corresponding controllable switches in the real experiment.
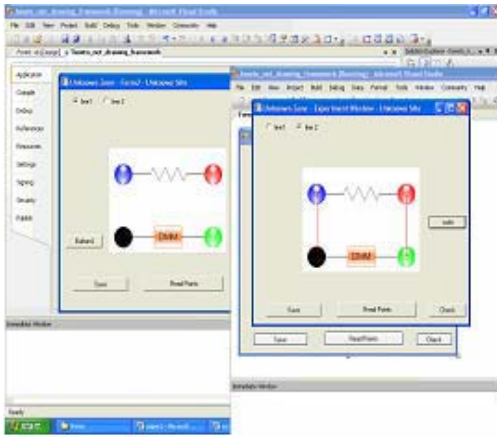
Fig. 4 Virtual components on the user-interface
(Experiment window)

VII. CONCLUSION AND FUTURE WORK

Before having started to develop collaborative working environments for remote experimentation, we found that it was necessary to consider other collaborative systems successfully applied in other fields such as air traffic and the military. The distributed e-collaborative system could be made of the following components: a server, web-based user-interfaces, a management component, a rule-based system (e-tutor), a recording component, and the experiment itself. The web-based user-interfaces as mediators between users (students and tutors) play a central role within the distributed e-collaborative system since it represents the remotely located physical experiment to the users. To design a user-interface ergonomically, there must be differentiation between the sciences of perception- and cognition-ergonomics. In an e-laboratory, the interaction between instructor and students are indirect and the communication between them takes place through any form of media. Therefore, we proposed the use of a chat tool, which was implemented in the programming language "vb.net" for allowing effective interaction between students and instructor as it is the case in real environments. Due to this, the students can receive feedback or any assistance needed, sampling studying in traditional classrooms. Since a remote human tutor can't be online every time to support students, it was necessary to implement an automated helping system (e-tutor) to support students, and to provide a feedback to them when they need clarification on their work. The e-tutor is realized as simplified rule-based system because our focus is mainly on collaborative systems and not on knowledge-based systems. The rules of the rule-based system consist of two parts: conditions and action. The e-tutor functions as an observer for students' actions manipulated on the experiment. Once the connections of the electronic elements on the virtual experiment are incorrect, the e-tutor displays a warning message and prevents contacting elements to be connected on the remote experiment board.

A wide variety of social factors can play a large part in online collaborative e-laboratory; namely, affecting the learner's motivation, the ability to participate in an experiment, as well as to communicate and coordinate with colleagues. Some of these factors include: cultural differences, language barriers specially for students who are not native speakers of the language, facility with written communication such as chat tools (synchronous), social presence such as feeling of connectedness and participation, relationship among students and the dialogue that results between students, providing students with the opportunity to test and refine their understanding in an ongoing process.

Once all of these factors are stimulated, the productivity of the students will be increased, leading to provide a positive learning and exchange of information between students. Accordingly, the learning process (environment) will also become more efficient. That is, an e-collaborative system environment is characterized as efficient when it enables the collaborating partners to exchange information through a coordinated communication. All in all, the synchronous approach is superior to the asynchronous one regarding instructional support. TABLE I [15] shows the differences between the conventional collaborative and internet-based e-collaborative learning environments.

Based on the results achieved in this paper, more complicated engineering and science experiments could be investigated. Access to the implemented experiment from any place by more than one student is possible enabled by the basic configuration of the implemented architecture. It would be interesting if we can test our ideas with more complicated experiments. Complicated engineering experiments with many electronic devices and equipments can be easily implemented through scaling by adding new programmable devices, electronic components and PC's. One way the complexity of experiments can be reduced is the usage of programmable devices, which can manage a large number of experiments. For new experiments, new programmable devices must be installed and used.

TABLE I
DIFFERENCES BETWEEN CONVENTIONAL COLLABORATIVE AND INTERNET-BASED E-COLLABORATIVE LEARNING ENVIRONMENTS [15]

conventional collaborative environments	e-collaborative learning environments
Instructor-centered	Learner-centered
Lecture-oriented	Collaborative and discussion-based
While teachers act as experts, students are perceived as novices	Student participates in team learning through learning from other learners and collaborates with the facilitator to create the learning process
Learning content is static	Content is dynamic
Emphasis is focused on evaluation and testing	Emphasis is focused on performance

It would be of great interest to measure how the introduction of complex experiments affects student/student interaction, the human tutor and the system; as well as whether the feedback returned from the simplified rule-based e-tutor to the students is satisfied and correct according to their mistakes manipulated on complex experiment circuits. Another problem that might appear through monitoring of complicated experiments is the clearness regarding inequality in task division between students that has been solved by means of color coding. Accordingly, a better version of the e-tutor knowledge-based techniques could be implemented to serve as an automated help system for user support in complex remote experimentation environments.

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