Cooperative Electronic Learning in Virtual Laboratories Through Forums

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***Abstract*—The student-centered teaching paradigm focuses on students engaged in learning high-order skills. Pedagogical research results suggest that the use of active learning within a cooperative environment is the best way to obtain these skills. In this context, the use of the Internet for these educational purposes—a concept known as electronic learning—can eliminate the physical barriers to cooperative learning. However, the implementation of such an electronic learning environment is often attempted using ad-hoc strategies that considerably limit its final impact and applicability. This work demonstrates how to design cooperative learning activities on the Internet by using basic principles derived from contemporary pedagogical research results. These activities were successfully applied in the context of forums repeated twice in two years in an artificial neural networks laboratory belonging to an engineering program.**

***Index Terms*—Cooperative learning, electronic learning (e-learning), forums, Internet, learning objects, virtual laboratory.**

I. Introduction

THE EMERGENCE of the information society has deeply transformed the nature of work in organizations. Ideas and knowledge are causing a rapid evolution in a changing, highly technological, and global economy [1]. In this context, the workplace is based on interdependent teams solving complex problems in which members must use high-order skills in order to contribute to teamwork [2]. Consequently, higher education must focus on enabling its students to participate in these increasingly demanding jobs.

Along these lines, the Accreditation Board for Engineering and Technology (ABET) has drafted a set of criteria for engineering, technology, and applied science programs. The requirements for these programs stipulate that graduates be able to perform and analyze experiments, apply experimental results, improve processes, apply creativity, work effectively in teams, and possess good communication skills, in addition to mastering the knowledge, techniques, skills, and tools required by their respective disciplines [3]. Accordingly, the goal of teaching must be that students learn and develop high-order skills [4]. In this new situation, information and communication technologies (ICTs), including the Internet, will facilitate the development of such a student-centered teaching paradigm [5].

Manuscript received July 22, 2002; revised May 22, 2004. This work was supported by the Universitat Politécnica de Catalunya (UPC) under a grant for innovative teaching.

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Digital Object Identifier 10.1109/TE.2004.837045

This paper presents a Web-based laboratory for an engineering course in which students' activities are structured cooperatively using basic principles derived from recent pedagogical research. The organization of this paper is as follows: Section II discusses the goals of higher education in the context of the information society, which leads to the presentation of the student-centered paradigm and the role that technology must play in order to support it. Section III introduces a conceptual framework to understanding the basic elements of a student-centered instructional method based on group work, cooperative learning, and the technological solution referred to as *electronic learning* (e-learning). Sections IV and V describe the results of two years of experience with cooperative e-learning in a virtual artificial neural networks (ANN) laboratory. Finally, Section VI reviews the main conclusions of this paper.

II. Higher Education in the Twenty-First Century

A. The Student-Centered Learning Paradigm

The new economy of the information society is based on obtaining and utilizing knowledge in innovative ways [1], which requires employees who have and use high-order skills (i.e., comprehension, communication, and reasoning skills). However, most students show basic skills that only enable them to solve simple problems. Consequently, only a small percentage will be able to face ill-posed and ambiguous problems that require critical or creative thinking. (This problem has also been previously reported in secondary schools [6].) Hence, teachers must create learning environments that help students to make the transition from basic to high-order skills. In this new scenario, the focus is not on teachers but the process of how the students learn [7].

In a student-centered model, teaching is focused on improving the way students learn so that they gain a deeper understanding [8], which then reflects on how they experience the world [9]. The conclusions of pedagogical research into how learning can be enhanced point to a major meta-principle: active learning [4]. Only students actively engaged in learning are likely to acquire high-order skills [10]. Table I summarizes the differences between teacher-centered and student-centered models. The former, anchored in behaviorism, considers students to be passive entities that teachers can shape as they want. In contrast, the student-centered model, based on constructivism, highlights the active role students play in their own learning process, and the role of teachers is facilitating and supportive. While learning according to the first model is individualistic and competitive, the notion of groups naturally

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TABLE I
TEACHER-CENTERED VERSUS STUDENT-CENTERED MODELS

Teacher-centered Model		**Student-centered Model**	
Teachers	**Students**	**Teachers**	**Students**
Are the performers	Are the spectators	Are the trainers	Are the active players
Transfer knowledge	Repeat this knowledge in exams	Both form a society for discovering and creating knowledge	
Are active	Are passive	Both are active	
Are focused on grading		Are focused on understanding	
Learning environment		**Learning environment**	
Individualistic and competitive		Cooperative or collaborative	

arises in the second through a cooperative [2] or collaborative [11] learning environment.

B. The Role of ICT in Higher Education

The use of ICT in higher education will entail the gradual disappearance of the limitations of space and time, which will result in a transition toward a student-centered model based on cooperative work. ICT systems have many facilities that support active students who experiment and investigate [12] in flexible learning environments, which range from standard distance education services to more advanced environments such as virtual learning communities [13] or other kinds of collaborative virtual environments [14]. The use of ICT in a student-centered model will promote [5] the following:

1) more intensive communication between students and teachers, through work and discussion groups supported by new communication tools;
2) better learning through the use of simulators;
3) the development of competence and practical skills by the students in the virtual research laboratories.

In this new scenario, the acquisition of high-order skills will become possible, thus causing a decrease in the gap between learners' skills and knowledge. Teachers in an ICT-based student-centered model will focus their efforts on helping students to transform information into knowledge and understanding through ongoing dialogue [8], [15].

III. A CONCEPTUAL FRAMEWORK FOR COOPERATIVE E-LEARNING

A. E-Learning: Principles and Elements

E-learning can be defined as learning through the use of digital material on the Internet. More precisely, the term *e-learning* refers to the use of Internet technology to deliver a wide spectrum of learning solutions with the goal of improving the knowledge and performance of the students involved. It is based on three principles [16].

1) It is networked.
2) It is delivered using standard Internet technology.
3) It is focused on the broadest view of learning, beyond the teacher-centered paradigm, and gives increased emphasis to informal and on-demand learning [17].

(Other terms related to e-learning are distance learning [18] and Web-based training [19], although these usually rely on more traditional forms of adult learning.) There are two main elements that make up an e-learning solution [16], described in the following paragraphs.

1) *The instructional strategy.* This provides the basic mechanisms for interaction between students and teachers. Learning scripts, like cooperative structures [20], can be employed for this purpose.
2) *The informational strategy.* This defines the way in which the content is organized. It is a new and promising way to electronically organize course content by using learning objects [21], which can be roughly defined as digital entities that are distributed via the Internet. They are made up of small learning components (i.e., chunks of information) that can be reused and assembled in different contexts in a way that is similar to how software engineering objects are made [22]. Several different standards for learning objects, which define learning object models, have emerged with the aim of helping educators to adopt an approach of learning based on this technology [23], [24]. This approach would involve a data structure to store and distribute quality multimedia training content.

One of the most interesting e-learning solutions for higher education is the e-laboratory, which provides students with the opportunity to put recently acquired knowledge and skills into practice by granting them unlimited Internet use [5]. Therefore, one can carry out extended laboratory experiments, and students can develop observation, problem solving, and interpretative skills using an approach similar to that of researchers [25]. There are two different kinds of e-laboratories: virtual and remote. Unlike remote laboratories, virtual laboratories have no

TABLE II
LISTSERV VERSUS ONLINE FORUMS

Topic	Listserv		Web-based Forums	
	Pros	Cons	Pros	Cons
Organization	Elective	Conversation becomes tangled	A history is kept of the conversation	They focus on everything
Communication	Messages are sent to e-mail accounts	Overloads e-mail accounts	Non-intrusive	Students must take the initiative
Technical requirements	Easy to contribute with an e-mail tool	Local storage is necessary	No local storage is necessary	Require students to use forum tools

physical reference; students use a simulator that reproduces a real situation or implements a computer-aided design (CAD) tool. An example of a simple implementation of a virtual laboratory is the applets embedded in a hypertext markup language (HTML) page.

B. Foundations for Cooperative e-Learning

Generally speaking, the use of the Internet in a student-centered model has a great deal of potential strengths, including [12], which are described in the following subsections.

1) Support for Group Work: Computer networking facilitates the implementation of cooperative learning, which is the instructional use of group work so that students improve both their own learning process and that of the other group members [26]. Cooperation involves teamwork to achieve shared goals, where group members seek results that are beneficial for the entire group. The use of computer-supported cooperative learning is currently an active area of research in adult education [27].

2) Articulated Communication: Students can send e-mails with questions to experts or classmates through their Intranet. This action compels them to state their needs in a concise and highly articulate way. Electronic forums (or structured discussion groups) are a popular form of computer-mediated conference [28], [29], which, unlike face-to-face meetings, provide for a mediated discussion of topics between the members of a group [9], which then promotes high-order thinking within a cooperative environment. A pedagogical benefit of e-forums stems from the possibility of maintaining a fruitful dialogue between teachers and students (as well as among the students themselves), which is, according to [9], mandatory for obtaining a pedagogical benefit from any technological medium. Within the context of traditional cooperative learning, the powerful nature of this dialogue has been already appreciated in peer tutoring. In particular, peer tutoring is based on the results of studies in cognition, which have revealed that one of the most effective resources for the cognitive restructuring of information is for students to explain it to someone else [30].

C. Creating Cooperative e-Tivities

The design of productive instructional activities in e-learning environments, i.e., e-activities, or *e-tivities* in short [31], requires taking several further elements into account because of the particularities of this technological medium. The author highlights those described in the following paragraphs.

1) Environment: Electronic meetings can be held either synchronously (i.e., in real time) or asynchronously (i.e., postings are staggered). Experts prefer the asynchronous environment since it is easier to manage and allows participants greater flexibility [13]. A number of technological solutions exist for setting up an e-tivity. In asynchronous environments, listservs and Web-based forums are the most widely employed [19]. In listservs, users send posts to a list containing the e-mail addresses of all the participants. Once the list server receives a message, it is immediately forwarded to all of the list members. In contrast, Web-based forums allow structured communication between participants through a Web browser. Table II reviews the advantages and drawbacks of the two approaches.

2) Time: In asynchronous meetings, participants can take their time to make a contribution. Hence, topics may need one to four weeks in order to achieve full participation [28].

3) Group Size: The number of participants must be controlled to manage participation and to avoid information overload. Reports have indicated that asynchronous groups can have as many as 20 or even 50 members, although the optimal group size depends on the type of e-tivity [28]. The big differences in size with respect to face-to-face groups could be explained if one bears in mind that not all the participants in an asynchronous environment contribute to a given topic. Accordingly, in a particular temporal window, the effective e-group that performs co-op tasks has a size typically much smaller than the whole e-class so that a greater number of students could be properly managed inside an e-group.

In order to properly design and analyze an e-tivity, a five-stage framework has been proposed based on the observation of the progress of the following highly successful e-tivities [28], [31]:

1) *access and motivation*—participants access the hardware and software and start using the platform;
2) *online socialization*—participants get used to making contributions in the e-environment, start to post messages, and get to know the rest of the community;
3) *access and motivation*—participants start to share information relevant to the course content;
4) *knowledge construction*—course-related group debates take place, and the interaction becomes more collaborative;
5) *development*—participants search for further benefits from the system to help them achieve personal goals.

In addition, an e-activity based on group work must be properly structured to avoid the "free rider effect" [30], [32], in which some participants do the majority of the work while others do little. In cooperative learning, teachers must maintain authority through the structure they give to tasks and groups in order to enable students to help one another to learn a series of concepts or information. Hence, students will be able to assume the role of teachers, classmates, and learners at the same time.

Two major schools of cooperative learning [20], [26] are based on the idea that cooperation can occur with little or no material designed specifically for the course. However, how contact will take place between team members and the criteria for assessment criteria do have to be planned. The interaction between the members of a group in a cooperative task is codified in free-content scripts called *structures*. The characterization and study of structures allows the systematic organization and design of cooperative learning lessons, independently of the course content [20]. However, as stressed in [33], co-op learning structures that employ a conceptual framework grounded in a set of principles are more powerful than direct cooperative methods since teachers can learn and use them as a pattern to restructure their activities into cooperative ones or to develop new structures. Such a framework for co-op e-tivities is discussed in the following paragraph.

According to pedagogical research in cooperative learning, a cooperative task must incorporate a variety of principles to which researchers give varying importance and relevance [20], [26], [30]. In addition, co-op tasks have been widely performed and analyzed in classrooms. Accordingly, the translation of these principles into a virtual environment must be done with caution and one must take into account the differences between those media. In the author's view, a cooperative e-tivity must incorporate a variety of co-op principles such as those outlined hereafter.

1) Positive Interdependence: If a benefit for one student is associated with gains for teammates, then students are positively interdependent [20]. Teachers can encourage positive interdependence in tasks by establishing mutual goals, joint rewards, shared resources, or complementary roles [26]. In particular, role playing is one of the most direct ways to implement positive interdependence and has been widely employed and analyzed in peer tutoring [30]. Roles stipulate what other group members expect from a fellow member and his or her own obligations [26]. Interdependent roles are those that aid group members in maintaining successful working interactions with others [2].

2) Promotive Interaction: Individual encouragement and mutual aid in achieving and completing tasks promoted by positive interdependence are essential to achieving social competence [32]. Promotive interaction, which encourages and facilitates group members' individual efforts [2], is best characterized by members' [32] 1) providing each other with effective help, 2) exchanging information more efficiently and effectively, 3) providing each other with feedback for improving performance, and 4) questioning each other's deductions to provide deeper insight into the material under examination.

3) Individual Accountability: Methods that do not provide an individual grade or product within the scope of the teamwork do not achieve significant gains [30]. Thus, teachers must assess the quality and quantity of each member's work to ensure that the results benefit both the individual and the group [26].

4) Group Processing: Group work is considered to be valuable when group members reflect on how well they are functioning [32]. Group processing can be defined as reflecting on a group session, such as 1) determining which member actions were useful and which were not and 2) following up correspondingly. The aim of group processing is to enhance and clarify group members' competence in the subject at hand. There are several ways of structuring group processing [2], among which the following are highlighted:

1) to monitor and evaluate the quality of the interaction among members as they work;
2) to give feedback to each group and its members;
3) to conduct a whole-class processing session by sharing the results of the observations.

IV. A Cooperative Laboratory: A Transition From Physical to Virtual

A. Academic Context

The laboratory experience described below took place during an artificial neural networks (ANNs) course taught at the School of Telecommunications Engineering of Barcelona (ETSETB), Barcelona, Spain, which has more than 2000 students and is one of the leading engineering schools in this field in Spain. Although the instructors of this course are currently active in ANN research [34], the course itself is not based on advanced theoretical content. Instead, its approach is eminently practical, with emphasis placed on students' obtaining an intuitive understanding of the main advances in the field, which is an interdisciplinary discipline built upon neuroscience, statistics, machine learning, and artificial intelligence. The course is for undergraduate students in the last years of their studies and entails a workload of four hours per week over four months' time. Students design an ANN project as their final work for the course, to which the laboratory sessions serve as an introduction.

B. Organization of the Laboratory

In the 2000–2001 academic year, the ANN laboratory sessions underwent a considerable change to overcome the rigidity and monotony that had characterized laboratory work until then. In past years, students focused their efforts on answering the questions posed in laboratory manuals. They systematically followed the detailed instructions in manuals to carry out experiments in a routine way and recorded their results as the questions required. The new system introduced three laboratory sessions that required physical presence (2 h/session) and three sessions in which laboratory work was performed via the Internet. Physical and virtual sessions were interrelated, and each pair comprised a thematic learning module in which an ANN model was studied. Laboratory sessions began one month after the beginning of the course to delay theoretical content from being introduced before its laboratory counterpart. The groups were made up of ten students, half the usual laboratory group size at the school.

In nonvirtual laboratory sessions, the instructor performed several brief lectures (5 min/lecture), using electronic slides that suggested topics that students could investigate in pairs with the help of a neural network simulator [35]. Students did not know the content of the sessions would be in advance. No manuals were used in conducting the experiments or in handling the simulator. Specific instructions for using the simulator were given on demand, as the need arose. At the end of the session, students filled in a question sheet related to the experiments they had performed. Then, in virtual laboratory sessions, a cooperative learning experience was conducted through a Web-based simulator, and the classmates interacted by connecting to a forum. (Several co-op approaches are currently working at this university, e.g., [36], but none of them relies on a virtual environment.)

C. Virtual Laboratories Based on Cooperative Electronic Forums

Students first conducted, in virtual laboratories, a series of experiments based on Java applets, which can be run either by accessing the course Web page or locally on a computer from a CD-ROM. They were given a brief description of how applets worked and the theoretical background for studying the ANN models used in the experiments that had been provided in previous class lectures and through some recommended reading. Subsequently, the students and the instructor simultaneously participated in a one-week asynchronous electronic forum using a listserv. The goal of the forum was for students to obtain a thorough understanding of ANN models through participating in a cooperative learning environment.

According to the conceptual framework introduced in the previous section, the forums were designed to incorporate the co-op e-principles outlined herafter.

1) Positive Interdependence: Students in the cooperative task were assigned to one of two complementary roles–either "inquisitor" or "replier." Inquisitors could ask questions in the forum and optionally answer posted questions, while repliers could answer questions posted by other classmates and optionally pose questions. Accordingly, a "replier's" answer to a posted question has a direct benefit for the "inquisitor" as well as other group members, which then enables successful working interactions among them. These roles, which can be understood as mediators for establishing a web of relationships in a structured discussion, have their precedent in several peer tutoring works of the 1980s [37], [38]. (Similar roles called "recaller" and "listener," which exhibited a lesser degree of interdependence, were applied in co-op tasks with success [37].) Students were notified that the questions that were posted might help them to understand the ANN models. However, students could ask simple questions regarding the simulator if they were unsure how it was used. One third of the class was assigned the role of inquisitor, while the rest (including the instructor) were assigned to the replier role. The instructor notified the students as to which roles they had been assigned at the start of the forum. Students were informed that the instructor would only take part in the forum when relevant questions were not answered or when the participation was not satisfactory.

2) Promotive Interaction: The roles of "inquisitor" and "replier" enable students to provide each other with effective assistance and serve to foment an effective exchange of information through the mediated and written contribution of forum posts. In these posts, students may also question one another's deductions if nested question–answer pairs are posted by the participants. In addition, inquisitors provide feedback to repliers that can be used to improve performance by submitting a written report at the end of each forum (see "Group Processing" subsection hereafter).

3) Individual Accountability: The assessment criteria, designed to make students individually accountable, were made public and based on students' fulfillment of their role in the forum and the degree and quality of their participation (Table III). The complementary character of both roles was properly balanced in assessment. If an inquisitor knew the answer to his or her question, he or she could then act as a teacher and send the answer later to complement his or her fellow group members' responses. (No restriction is given on answering one's own questions once no reply is posted by classmates.) On the contrary, if an inquisitor does not know an answer, he or she then acts as a student and asks for input him or herself. He or she can then go on to complement fellow members' answers according to his or her updated understanding of his or her own answer. On the other hand, the complexity of repliers' having to answer their fellows' questions is duly recognized. For instance, if a replier sends two messages that contain correct answers to questions, he or she earns eight points (goals 1 and 2). Likewise, the inquisitor's role as teacher is suitably acknowledged as he or she must exhibit a deeper understanding of the material. Consequently, an inquisitor, by sending two messages that pose questions and later sending replies that complement his or her fellow members' answers to them, earns eight points as well. In addition, students must post good questions in order to earn a bonus on their assessment (goal 3). This last constraint forces inquisitors and repliers to make relevant questions to achieve the maximum grade.

4) Group Processing: Once the forum had concluded, the inquisitors each wrote a forum report. These reports could include the following elements:

1) all the contributions posted in the forum;
2) a discussion section in which wrong answers could be detected and unanswered questions could be addressed;

TABLE III
INDIVIDUAL ASSESSMENT CRITERIA FOR FORUM PARTICIPATION

Goals	Points to assign[1]
1. The student has sent messages[2] according to his/her role:	
a) only one message	2
b) more than one message	4
2. The student has correctly answered messages:	
a) only one message	2
b) more than one message	4
3. The student has raised relevant questions that have to do with the understanding of content	2

[1] Grades are computed out of 10 points
[2] A message must contain one of the following possibilities: two questions, two answers, or a question and an answer.

TABLE IV
ASSESSMENT CRITERIA FOR FORUM REPORTS

Goals	Points to assign
The report includes all the sections with an accurate syntax and presentation.	2
The report includes a relevant list of conclusions.	2
The report includes a discussion section in which	
- Errors in the questions/answers posted in the forum are detected;	2
- Interesting new question/answer pairs are formulated;	2
- Replies to unanswered questions are formulated.	2

3) an assessment section that graded the participation of all the group members;
4) a section for comments in which students made proposals for improvements to the forum and stressed its positive (or negative) aspects;
5) a conclusion section that reviewed the most important topics covered and the key ideas of the forum.

Then, an anonymous classmate and the instructor reviewed this summary report, both of them using the same public assessment criteria (Table IV). The review form, which was sent to the author, included a grade and the reviewer's justification. Carrying out a review was mandatory in order to get a grade for the laboratory sessions. In this way, not just teachers but also students checked and assessed the quality of the participation of group members, providing the added benefit of automatic feedback.

D. Results

Students' participation was analyzed using the following three different criteria:

1) how well they adapted to laboratory work (Table V) based on the Students' Evaluation of Educational Quality (SEEQ) for Laboratory Work in Science provided by the Centre for Educational Advancement at the Curtin University of Technology, Western Australia [39] (the standard SEEQ form, which was originally developed by Herbert Marsh during the late 1970s [40] and is now an established and useful feedback tool for teachers is not used, since it is too coarse for assessment of laboratory work);
2) several statistics, such as mean participant contributions to forums (Table VI), the percentage of questions posted

TABLE V
RESULTS IN A SUBSET OF THE LABORATORY SEEQ FORM

Questions	Strongly Disagree	Disagree	Neutral	Agree	Strongly agree
1. The laboratory classes were intellectually stimulating and challenging.	0%	0%	27%	37%	36%
2. The instructor helped me solve my own problems rather than doing it all for me.	0%	0%	18%	64%	18%
3. We were encouraged to work cooperatively.	0%	0%	18%	55%	27%
4. I was free to ask questions or express an opinion.	0%	0%	9%	73%	18%
5. Post-laboratory discussion helped me understand the purpose and results of the lab exercise.	0%	0%	20%	40%	40%
6. Assessment of laboratory reports took into consideration both a critical analysis of results and proper reporting of the results obtained.	0%	0%	17%	83%	0%
7. Assessment of laboratory reports took into consideration clear written expression.	0%	0%	17%	83%	0%
8. Good laboratory practice was rewarded in the assessment procedure.	0%	0%	33%	67%	0%
9. Where appropriate, opportunities were provided for creative experimentation.	0%	0%	29%	57%	14%
10. Where suitable, experimental work was presented as a challenge.	0%	0%	33%	50%	17%

according to Bloom's cognitive levels (Table VII), and the percentage of students that at the end of the forum reached one of Salmon's five stages [28], [31];

3) written comments extracted from forum reports.

Once students had taken their first steps and became more confident in posting messages, they got more and more involved in the cooperative laboratory approach. At the end of the course, they were very satisfied, as the results of the laboratory SEEQ form shows. According to these forms, most of the students felt that challenging and creative experimentation and the critical analysis of results had been promoted within a cooperative environment (see questions 1, 3, 6, 9, and 10 in Table V). Students also commented in their written forum reports that they thought the forum allowed active processing, mediated contribution, and a better understanding of theoretical content.

In the electronic forums, students passed through the *access/motivation and online socialization stages* to the *information exchange stage* in a few days during the first forum. Inquisitors tended to act as moderators, directing the discussion toward various topics. However, once the discussion was established, students tended to forget their role since each participant posted on an average more than two questions and answers (Table VI). (In particular, when top students acted as inquisitors, highly cooperative dialogues tended to emerge since these students often posed very difficult questions, which increased the interest of their mates; consequently, their interaction became more intertwined.) A considerable percentage of the messages posted were very relevant: over 70% were related to high-order skills, i.e., application, analysis, synthesis, and evaluation skills (Table VII). Furthermore, written reports

TABLE VI
MEAN PARTICIPANT CONTRIBUTION TO FORUMS

Mean participant contribution	First year			Second year	
	Forum1	Forum2	Forum3	Forum1	Forum2
Posted questions	2.5	2.1	2.2	2.3	2.0
Answers	3.0	2.5	2.3	3.7	3.1
Unsolved questions	0.1	0.5	0.5	0.2	0.3
Group interaction	1.25	1.65	1.32	1.70	1.83

were notably accurate; students obtained an average of seven out of ten points in the instructor's reviews. Students' review of classmates' reports was highly rigorous; the average grade was 6.2.

In spite of the promising results, several negative points emerged. Forums were necessarily lengthened to 15 days in order to overcome students' limited access to the Internet and to give them more time to experiment with the simulator. Moreover, the interaction was between pairs more often than was desirable. As a quantitative measure of this effect, a computation was made for a *group interaction* statistic defined as the number of answers divided by the number of questions answered (1.25 and 1.32 in forums 1 and 3, respectively) (Table VI). Thus, as communication largely took place between pairs, less than half of the students were involved in the *knowledge construction stage* (40% of the whole class), which is of a highly cooperative nature, and even fewer (20%) in the *development stage*, the last step, in which students use group knowledge construction for their personal interests. These results can be, in part, explained by the difficulties for group communication that naturally arise in an unstructured medium like listserv, in which conversation easily becomes tangled (Table II).

V. A Cooperative Virtual Laboratory

A. Organization of the Laboratory

During the following academic year (2001–2002), further steps were taken to implement a complete cooperative virtual laboratory. Two major improvements were included, which are described hereafter.

1) Learning Objects: The content of nonvirtual laboratory sessions of the previous year was transformed into a fully electronic format, which consisted of two digital lessons based on learning objects. Each object was made up of an introduction with slides and five to seven pairs of theoretical assignments (three pages or less) and simulations that presented a concept to be learned. The learning objects were implemented using an HTML page with links to the introduction slides and the theoretical documents and simulations. Unlike the first year, the number of forums was decreased by one, and an additional week was added to each forum so that students could study learning objects through personal work and the e-forum, which had the cooperative learning structure described in Section IV. Accordingly, as the overall time allotted to forum activities each year was the same (six weeks), fair comparisons can be made between both years.

2) Web-Based Forums: In the first edition, e-mail interaction seemed to pose a major obstacle to achieving highly cooperative work. Hence, a Web-based forum was used through an e-learning platform [41]. In addition, the forum workload was reduced. Students were required to write a report that reviewed only the impact of their personal contribution. The instructor adopted the same "replier" role and also acted as an e-moderator, responsible for introducing and concluding the forum by reviewing the most important topics covered.

B. Results

An evaluation was made between the first course edition and the second one. In particular, the improvements of the second year were tested and analyzed in comparison with those achieved in the first year within an experimental setting that can be regarded as a posttest only-control group design, according to Campbell and Stanley's terminology [42]. In such an experimental setting, a group (selected at random) that has experienced a particular event is compared with another random group (the control group), which had or had not experienced another event. Here, the students of the first year were assigned to the control group, and the others were assigned to the group going under the test. In addition, in order to collect some data from these two events, a test was given after events have been produced (denoted as a posttest). In this case, an intact class was selected instead of pure randomization of groups, which only reduced partially the random effect in the choice of groups.

Remarkable improvements were made on the previous experience. Forum discussion was clearly limited to the content of the learning object. Most students reached the *knowledge construction stage*, which can be quantified by several factors reflected in Table VI. First, group interaction was greater than in the first year (1.7 and 1.83 for the first and second forum, respectively, of the second year in comparison with 1.25, 1.65, and 1.32 of the first year). In addition, in this second year, group processing was improved as the course progressed. Furthermore, the number of unanswered questions decreased, and the posted message size increased by a factor of two as the forum progressed.

An exact analysis of the results of Table VII was avoided since group dynamics in the forums and the particular contents

TABLE VII
CLASSIFICATION OF QUESTION IN BLOOM'S COGNITIVE LEVELS

Questions about (%)	First year			Second year	
	Forum1	Forum2	Forum3	Forum1	Forum2
Knowledge (that which can be remembered)	21.4	17.4	12.5	14.3	21.4
Manipulation (ability to rearticulate knowledge)	10.7	13.0	16.7	28.6	28.6
Application (ability to apply knowledge in new situations)	7.1	8.7	12.5	14.3	7.1
Analysis (ability to break down a problem into parts and find relationships between each one)	32.1	26.1	29.2	21.4	28.6
Synthesis (ability to combine separate things into a whole)	3.6	13.0	16.7	0.0	0.0
Evaluation (ability to make a judgment)	25.0	21.7	12.5	21.4	14.3

of the material studied would inevitably narrow the conclusions of the experience to a specific topic (i.e., ANNs). However, if one simply breaks the answers down along the lines of the difference between "rote learning" (level 1 of Bloom's taxonomy) and "meaningful learning" (level 2 and above), each year more than 78% of the questions posted moved beyond "knowledge facts." In addition, during the second year, unlike the year before, questions about knowledge and manipulation represented 50% of the total because of the study of learning objects. However, the other half of the posted questions, related to high-order skills, were considerably better defined than the year before. Another result of learning objects was the disappearance of synthesis questions since a tool for synthesizing ANNs was not present in them.

During the second year of experimentation, as a consequence of better group processing, a significant proportion of students (50%) got involved in the development stage. Again, students' comments in written reports coincided with a positive evaluation of the forum experience. However, some students felt limited by the e-forum. Consequently, physical meetings were organized to achieve a deeper discussion level using a limited amount of time, in agreement with one of the prescribed ways of better structuring group processing (Section III-C). Another possibility, left for further exploration, is the complementary use of synchronous e-meetings instead of physical ones using chats as a means of providing a better conclusion to the forum.

VI. LESSONS LEARNED

A number of conclusions can be drawn from the cooperative ANN laboratory, concerning the topics described hereafter.

1) Open-Ended Enquiry e-Laboratories: In the student-centered paradigm, teachers and students tend to form a learning community (Table I) so that the traditional authority figure played by teachers disappears. In this case study, this fact has been explicitly taken into account in the design of the forum by assigning teachers to the more passive role (replier) and thus emphasizing the active role of students as inquisitors. Students' behavior also reflects the freedom they sense in their e-learning environment, as is reflected by the SEEQ form (Table V). In this context, cooperative e-forums offer students opportunities to construct knowledge for themselves through e-interaction with classmates under the guidance of e-moderators. Asynchronous Web-based forums give students time to reflect on issues before they add their own contribution. These are organized as posted messages, which encourage group discussion. Group processing becomes possible once the instructional strategy of the e-laboratory, based on a learning structure that implements cooperative principles, has been designed (Section III). In the informal learning framework presented here, the acquisition of high-order skills became a reality, and students involved themselves in pseudoresearch laboratory work.

2) Learning Objects: An information strategy for the e-laboratory based on learning objects helped students to access information in a highly structured manner and to improve the quality of the forum discussion.

3) Scalability: A common complaint about shifting from the traditional teaching paradigm is the increase in workload for teachers. However, this work suggests that this increase can be mitigated if the students' responsibilities in the course are augmented. As students became more and more involved in the design, results and assessment of the course, the teachers' role was made easier. This work shows that students can also perform some of the tasks that were previously performed by teachers only, e.g., assessment, since most of them perform these tasks—with extreme rigor—along the lines of the assessment criteria established by the instructors.

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