Multiple Case Studies to Enhance Project-Based Learning in a Computer Architecture Course

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***Abstract*—The IEEE/Association for Computing Machinery (ACM) Computing Curricula and the Accreditation Board of Engineering and Technology (ABET) Evaluation Criteria 2000 emphasize the use of recurrent concepts and system design/evaluation through projects and case studies in the curriculum of Computer and Electrical Engineering. In addition, efficient teamwork, autonomy, and initiative are commonly required qualifications for a professional in this field. Project-based learning approaches that require the students to handle realistic case studies are adequate to pursue these objectives. However, these pedagogical approaches tend to be rejected because they promote deep learning but focus on a restricted set of concepts, whereas many engineering curricula require a broad range of concepts to be covered in each course. The introduction of multiple case studies carried out simultaneously in the same course by different teams of students can broaden the set of concepts studied, but collaboration at different levels must be strongly enforced to achieve effective learning. This paper describes a multiple-case-study project design that has been applied to a computer architecture course for four years. After systematically evaluating the experience, the authors conclude that students achieve a deep learning of the concepts required in their own case study, while they are able to generalize their knowledge to case studies of different characteristics from those considered during the course. Furthermore, a number of collaborative skills and attitudes are developed as a consequence of the proposed environment based on multiple levels of collaboration.**

***Index Terms*—Collaborative learning, computer architecture, computer-supported collaborative learning (CSCL), project-based learning, system design and evaluation.**

I. Introduction

ELECTRICAL and computer engineers need to develop skills for the design and evaluation of computer systems. Project-based learning methods applied to the resolution of case studies seem to be an adequate approach [1], [2]. Students learn to face realistic, complex problems, rather than academic, simplified tasks, while they develop skills for autonomous learning and group work [3]. These objectives are encouraged by many engineering curricula designs, such as IEEE/Association for Computing Machinery (ACM) Computer Curricula 2001 [4] and accreditation institutions [5], [6]. However, the application of these methods in traditional educational contexts, where the curriculum is mainly oriented to the transmission of concepts from a teacher to a group of students, is very difficult. The main drawbacks in applying project-based methods stem from the need to cover the broad range of contents that these fields demand to meet the curriculum standards [7] and from the difficulties students have to develop adequate work plans to handle project complexity [8]. Several approaches have tried to overcome these problems (summary in [1]), such as [9], which proposes the use of *jigsaw* techniques: in a single project, groups of students become "experts" in a part of the project and then join together to solve it. However, this approach requires the project to be divided in parts that can be studied independently, but also complement each other well in the search of the project solution, a situation that is not always possible.

In a different approach, the pedagogical design could include several case studies to be carried out by different teams of students during the course. This way, students are expected to collaborate and discuss with others having a different case study, thus achieving a broader view of the concepts in the course, but their learning would still be deep because of the focus put in their own case study.

However, this pedagogical design relies on strong collaboration that must be carefully promoted by educational designers. Thus, some of the tasks in the project could be common among different case studies or dependent on the others (i.e., writing report sections devoted to comparison between case studies). Furthermore, different means of interacting and collaborating must be provided and planned, such as public defenses of the state of the project by each team, or Web-based repositories, in order to have an effective exchange of ideas [10]. In this sense, the facilities provided by computer networks for collaboration [11] can be exploited to allow students to interact at different levels, i.e., with their team mates, with other teams having the same case study, and finally, with teams with different case studies. This collaboration has been used in many other computer-supported collaborative learning (CSCL) designs [12].

This paper aims at overcoming some restrictions of educational designs based on a single case study, through the use of five different case studies in a design-and-evaluation project for a computer architecture course. These case studies are to be developed by distinct teams during the course, but common or dependent tasks are formulated. Thus, collaboration at different levels is encouraged by the pedagogical design, supported by networked tools. This way, students could achieve deep learning, while having a broad view of computer-architecture-related

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TABLE I
COURSES RELATED TO THE COMPUTER ARCHITECTURE COURSE OFFERED IN THE TELECOMMUNICATIONS ENGINEERING CURRICULUM PRIOR TO IT

Name of course	Type	Year	Semester	Related contents
Programming	Core	1st	Fall	Internal data representation, Bool s algebra, basic computer architecture (von Neumann s), programming languages, compilers, structured programming, assignments in C
Computer fundamentals	Core	2nd	Spring	Description levels, functional units, register transfer levels, instruction sets, I/O concepts, operating systems basics
Computers	Elective	3rd	Spring	Programming with system calls
Microprocessors	Core	3rd	Fall	Microprocessors, I/O techniques, I/O devices, controller design with microprocessors
Economy and management	Elective	3rd	Spring	Market economies fundamentals, economic environment of the enterprises, management in telecommunications
Several courses	Both	1-5	Both	Networking hardware, protocols, distributed applications, etc.

contents. Furthermore, they are expected to develop skills, such as autonomous learning, critical thinking, and collaboration.

The remainder of this paper is organized as follows. Section II details the educational design. Section III describes the evaluation methodology and discusses in detail the results from this evaluation. Finally, Section IV draws some general recommendations and conclusions.

II. THE EDUCATIONAL DESIGN

A. The Educational Context

The experience reported in the present paper takes place in an undergraduate computer architecture course. This course is part of the core body of knowledge in the telecommunications engineering curriculum in Spanish universities. It is placed in the fall semester of the fourth year (out of five) and is comprised of 30 lecture hours and 60 laboratory hours. Within the curriculum, the course is the last of a branch on computing topics that covers programming fundamentals, operating systems, and computer architecture (Table I). In brief, the course covers computer organization, cost–performance analysis, processor architectures, parallel machines, memory hierarchies, input–output schemes, and a review of different approaches in operating systems. Considering the IEEE/ACM Computing Curricula 2001 [4], units AR3 through AR9, OS1, and OS2 are covered in the course.

Since students are approaching the end of their undergraduate studies, they expect to find activities closely related to real-world problems. Besides, they have attended several networking and economics courses that they should contextualize. These facts make this course suitable for project-based learning, based on the resolution of realistic problems (case studies) as reported in the literature by several research studies for similar learning scenarios [13]. Indeed, design and evaluation of computer systems is a task in which different opinions and solutions can be valid; teamwork is necessary to perform efficiently such a complex task; and technical and commercial information and simulators are available in the public domain. Significantly, a very popular textbook on computer architecture [14] promotes a quantitative approach to the study of the field which is especially suitable in this context.

Therefore, the course is based on a design and evaluation project of computing systems, as described below.

B. Pedagogical Design

A large project, divided into three subprojects of about four weeks each, is planned for the 13-week-long semester and carried out in the 60 laboratory hours (the 30 lecture hours follow a traditional scheme). Students are organized in groups of two people and assume different roles within the project. First, they play consultants of a consulting firm that must study some market sector and the existing computing technology, in order to assist a *customer* to purchase a computing system for his business problem. This *customer* corresponds to the case study they have to solve. In addition, students role-play as engineers of a computer manufacturer, which must design and evaluate the different subsystems. Teachers play the roles of the customer, the director of the consultants' team, and the Chief Executive Officer (CEO) of the manufacturing company.

Instead of proposing only one customer (i.e., case study) for all teams, five different customers are considered each year, but each group of students works with only one given customer. Groups of students have different customers enriching the learning process by the need of contrasting requirements and solutions. This approach also aims at facilitating the development of critical positions toward different technologies, instead of absolute preferences for a particular one. In order to broaden the range of studied technologies, the proposed customers correspond to different sectors that require different solutions, such as the assembly of genome sequences (supercomputing), an Internet-based music distribution (multiprocessing high-end servers), or a museum tour (wireless devices). In addition, case studies are renewed each year, introducing hot topics in technology and business worlds.

The course is organized in three subprojects, as summarized in Table II. The lectures are planned to provide students with the basic theoretical background needed to fulfill the assignments of each subproject.

TABLE II
SUMMARY OF THE EDUCATIONAL PROJECT

Milestone	Contents	Activities	Outcomes
Subproject 1, intermediate review	Technical vocabulary, technical requirements, performance/cost trade-off	Interview customer, read documentation, determine customer needs	Form completed and answers published, public discussion
Subproject 1, final review	Benchmarking	Benchmark laboratory machines with Dhrystone, Whetstone, SPEC CPU95, TeX, Spice and gcc. Model customer workload with these programs and recommend machine for customer	Form completed and answers published, public discussion, report delivered
Subproject 2, intermediate review	Instruction sets, CISC vs RISC, pipelining	Model customer workload with a benchmark in DLX code, simulate using `dlxsim` and `dlxview`, provide design guidelines for CPU	Form completed and answers published, public discussion
Subproject 2, final review	Multiple issue: superscalar, VLIW, high level parallelism	Simulate using `dlxview` and `superdlx`, propose an initial CPU architecture for customer	Form completed and answers published, public discussion, report delivered
Subproject 3, intermediate review	Memory caching, memory hierarchy	Simulate using `dineroIV`, recommend memory configuration for customer	Form completed and answers published, public discussion
Subproject 3, final review	Virtual memory, input/output, operating systems and applications (brief reminder)	Read commercial documentation, recommend whole system for customer	Form completed and answers published, public discussion, report delivered among four groups (all with the same customer)

The first subproject starts with a requirement analysis for the customer's business and an estimation of the computational workload. This task is supported by the first lectures, which introduce the fundamentals of computer design (chapter 1 [14]) and a number of technical requirements, such as scalability, cost, availability, response time, robustness, etc. This task involves high-level knowledge and not technical details on the processor design, which are introduced later. After determining the requirements, students must estimate the computational workload of their customer to perform a cost–performance analysis of the laboratory machines using existing benchmarks. The consulting firm employs these results to provide a preliminary recommendation. In this subproject, students not only learn to specify technical requirements, but also to benchmark machines and use the results for a fair cost–performance comparison.

The recommendation of the students will be based both in the performance of real or simulated processors for their estimated workload and in the rest of the technical requirements. For example, a wireless device to guide visitors of a museum may have to decode images, involving floating-point operations, but it also has to be small with reduced energy consumption. This requirement restricts the number of operational units or the memory size. A reduced memory size may also support the students in recommending a complex instruction set computer (CISC) architecture because programs will be much more compact, though they only have simulated reduced instruction set computer (RISC) processors.

The second subproject works with processor architectures and parallel machines. The engineers of the computer manufacturing company design a benchmark in DLX (DeLuXe) code [14], characterizing their customer workload. Then, they use simulators to evaluate the most appropriate alternatives.

In addition, lectures introduce other types of high-level parallelism (process, task) and other types of parallel solutions (clusters, grids). Using simulation results on one hand, and arguing on the matching between customer requirements and theoretical solution capabilities on the other, the students must discuss the convenience of particular parallel solutions for their customer. In conclusion, by the end of the second subproject, the consultants must propose an initial central processing unit (CPU) architecture for the customer, ranging from a scalar single-processor machine to any type of distributed system.

At the end of the third subproject, consultants must deliver an overall solution for their customers. Therefore, during the last subproject, they work with the remaining subsystems (memory hierarchy, input–output schemes, operating system, and application software) and refine previous work. Except for the memory hierarchy, this study is analytical because of the lack of simulators. To cope better with this more demanding task, the students join during this period in larger groups composed of four of the former teams (pairs) that were working on the same case study.

To enforce collaboration, teachers require each group of students to compare in their reports the solution they propose for their customer with the solutions proposed by other pairs dealing with the same customer and by pairs dealing with a different customer. In addition, collaboration is encouraged and assisted with computer-supported collaborative tools, such as Basic Support for Cooperative Work (BSCW) [15], Quest [16], and e-mail that allows them to share information and discuss with groups in other sessions.

Table II also shows that each subproject has two milestones. Before each of them, students fill out a form concerning their partial solution up to that moment. Using Quest, everyone's answers are published on the Web, and a few days later, a class-level discussion is held on these data (called a *review*). The intermediate review serves as a checkpoint where preliminary activities are discussed, and the teacher can bring into focus important issues that may have been disregarded. The final review also includes a public discussion, but afterwards a formal technical report must be delivered by each group.

III. Evaluation of the Project

A. Evaluation Methodology

The project described in this paper has been ongoing for four years. Two teachers—one full-time professor and one part-time assistant—were involved in the lectures and in the laboratory sessions. The size of the courses to which the project has been applied ranges from 120 to 130 students. In addition, other staff were involved in the course, as part of an educational research project, performing a systematic evaluation of the course. Therefore, during these years, both the course and its evaluation have been increasingly improved. This section explains the evaluation method used to support the conclusions presented later in this paper. Practitioner readers should be aware that though evaluation helps to better understand the process, it is not strictly necessary or could be carried out with less detail.

The evaluation of the success of a complex setting like the one presented in this paper must take into account many factors that cannot be easily quantified. This list includes individual characteristics of learners and educators, social and cultural issues, the impact of computers and distributed system technologies, and the very achievement of the learning objectives. To consider all these aspects, a mixed evaluation method [17] has been proposed. Quantitative methods allow detection of general trends related to students' opinions and attitudes, while qualitative methods allow the evaluator to understand these trends better by introducing context issues and considering participants' perspective. Therefore, both methods are complementary, since one can reveal issues that can be further researched with the other. Data analyzed with these methods come from a number of different sources, as summarized in Table III.

TABLE III
DATA SOURCES FOR THE EVALUATION OF THE PROJECT, AND LABELS USED IN THE TEXT TO QUOTE THEM. THE VALUES USED IN THE LABELS CORRESPOND TO THE SOURCES AND FREQUENCIES INDICATED IN THE FIRST COLUMN

Source and frequency	Type of data	Labels
Questionnaires before (Initial) and after the course (Final), and twice every subproject (SPxa and SPxb), with x standing for 1, 2, or 3	Quantitative ratings and qualitative explanations	[Quest-Initial], [Quest-SP1a], [Quest-SP1b], [Quest-SP2a], [Quest-SP2b], [Quest-SP3a], [Quest-SP3b], [Quest-Final]
Focus group interviews before and after the course, and once every subproject	Qualitative students opinions, with the same frequencies than the questionnaires (first row)	[Focus-Initial], [Focus-SP1], [Focus-SP2], [Focus-SP3], [Focus-Final]
BSCW logs	Document access	[BSCW]

Students' opinions on their learning and the development of the project are collected in every milestone in the project (i.e., six times throughout the course). In addition, two broader questionnaires are passed before the course starts and after it ends. These questionnaires collect quantitative ratings of several issues, as well as qualitative explanations of the ratings. All students can also express their concerns about the educational project in a free form submitted with each report. Among the issues considered in these questionnaires were aspects related to the classroom context, to the collaboration experience of the students before and during the experience, to the resources used to support collaboration, and to the educational project itself. In addition, a focus group of volunteers (about ten each year) are interviewed five times during the course by two educational researchers. The teachers in the course do not attend the interviews. These interviews provide subjective opinions stated by students in a more relaxed, free environment.

Quantitative data coming from these sources are preprocessed with general statistic packages and then used to support and guide the analysis of other data. Qualitative data are structured into *categories* of study (e.g., intergroup collaboration/sharing documents), allowing for an organized interpretation of the arguments concerning these categories. This process is supported by a qualitative analysis tool [18].

Further data regarding the interactions are collected from the log files provided by BSCW (e.g., who reads or annotates whose documents). All these data can be interpreted through social network analysis (SNA) [19], a method to describe both numerically and pictorially patterns of relationships among actors and to analyze the structure of these patterns.

More information on this mixed-evaluation approach and the tools employed to collect data can be found in [20].

B. Results and Discussion

The educational project described in this paper was designed to overcome some of the limitations of project experiences, specifically the restricted scope that they generally impose, and to promote collaboration and other skills that will become necessary in the future professional life of the students. Table IV summarizes the main conclusions of the evaluation of the educational process that are discussed in more detail throughout this section.

As a main objective, the multiple-case-study project-based approach pursues that *students achieve a deep learning of concepts and abilities, but broad in scope*, as they get strongly involved in a real-world system design and evaluation project.

A first quantitative impression on the achievement of this objective comes from the success rate at the final exam. In one of its parts, a new customer is described. Then, students are asked a number of questions, such as the following: Which are the requirements or the importance of one particular requirement for this customer? Which are the types of parallelism expected in the workload? and What would be a general recommendation for a CPU or for the overall system? Last semester, the customer in the exam was a scientific project information and submission Website, which resembles one of the customers in the course (the Internet-based music distribution) and is totally different to some of the other customers. Not only did 86% of the students pass the exam, but also no significant advantage was displayed on the marks achieved by students working with the music distribution customer during the project (averaging 22 out of 32 points for that question) over the rest of the students (averaging 20).

TABLE IV
MAIN CONCLUSIONS OFFERED BY THE RESEARCH CARRIED OUT ALONG WITH THE EDUCATIONAL PROJECT

Pedagogical method	Results	Support data
Design the educational project carefully - different case studies with similar tasks, relating to students future professional life or to current industry and research trends; force comparison and collaboration with students with different case studies.	Learning is deep and broad in scope.	Based on the analysis of focus group interviews, and in the fact that in the exam students generalize well to a new mini-case study.
Include tasks depending on knowledge of other case studies, and tasks to be done in the groups joining several pairs.	Collaboration increases in response to common or dependent tasks.	Based on the denser collaboration networks for the period of writing the third report, and on the improvements observed in the comparatives between customers made by the students.
Publish forms with time to think about the answers; publish results with time before the review; develop a public review, focusing on apparent contradictions.	Filling out forms, publishing results, and reviewing them helps to know each other s work.	Supported on questionnaires and focus group interviews.
Become a *knowledge facilitator* - motivate, introduce deadlines. Propose tasks solvable by the team but not by a single member.	Students learn to self-organize and plan.	Based on the analysis of questionnaires.
Force collaboration by defining common tasks supported by tools and activities that promote interaction.	Students develop skills related to collaboration.	Questionnaires and social networks show that interaction increases.

However, to actually involve students in knowing about other customers, collaboration must be strongly motivated. In this educational setting, different means were used with this purpose, providing tools and motivations to share information and planning activities to be solved in a larger group.

The *computational support to share documents through BSCW has been revealed as important*, even in a face-to-face classroom setting. Students are encouraged to publish short summaries of their experiences in the laboratory session, especially if they talked to the teacher. In the questionnaires, some students stated that they "consider very useful the fact that summaries of the work session are published in BSCW, though they should be posted more frequently [Quest – SP1b]." Others state that "sharing and discussing ideas with others always enriches our knowledge and their knowledge. This time the telematic tools (BSCW) had a very important role [Quest – SP2b]." The use of BSCW grew, especially toward the third subproject when four teams must coordinate to produce a single report, as reported by the social networks displayed in Fig. 1, which represent the *indirect links* between the users (teams) that created a document and those that read it (BSCW). One can see that the network at the intermediate project was scarce and very centralized around a single actor (the teacher, displayed as a circle); at the final project, it is more dense and less dependent on the teacher. One can also observe that students did not interact closely with others having the same case study in the intermediate project, while in the final project teams with the same case study worked together more.

Although BSCW provides a means to share documents, no specific task depends on this feature; therefore, some students may use this facility sparsely. One of the most successful ways to encourage students to share their own results and ideas and get interested in those from others is to ask them to *fill out forms on the subproject contents and make all answers public* in the Web, easily achieved with Quest [16]. Students must study those answers since after a few days a class-level debate is held, mediated by the teacher. In this debate, students argue about their results and proposals, getting a critical view of different technologies and broadening their knowledge. Some students considered "interesting to observe the work and results of other groups, having the same or different customer, to check our coincidence or difference [Quest – SP3b]."

To further encourage the use of this shared information, *a mandatory comparison of solutions to different customers must be included in the reports* after the first and second subprojects. In the first subproject, this comparison is generally quite weak, while in the second it is supported by better arguments. Quantitatively, the average marking of this section evolved from 2.38 (out of five points) in the first subproject to 2.62 in the second, showing a slight improvement, especially considering that the grading of the first subproject is more relaxed.

Finally, having common tasks to solve can generally boost collaboration. In this educational setting, *the report after the third subproject must be collaboratively produced* among four groups having the same case study. They have to make a final recommendation for the CPU, starting from the four different solutions they proposed in previous subprojects. This decision causes further discussion of the arguments supporting each of the alternatives. As one student states in an interview, "one of the new things I liked is that merging ideas does not mean to choose one out of the four [Focus – SP3]." The report, however, requires recommendations on many other issues, such as memory hierarchy, input–output design, and operating system and application software. Although they are not so deeply covered, the reality is that eight people offer their own view, enriching the decision process. Significantly, some groups stated in the questionnaire passed by the end of the course that "it is difficult to understand by oneself every issue involved in the last subproject, sharing ideas is critical for all the people to see all the issues.

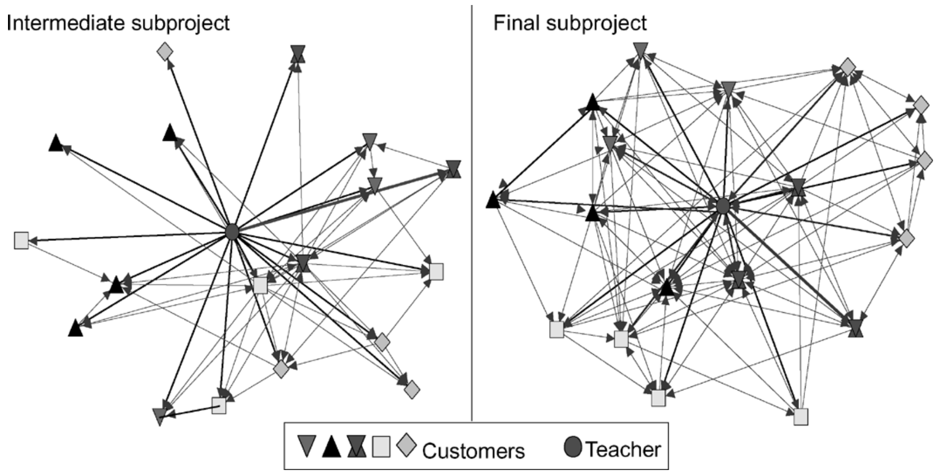

Fig. 1. Social networks showing the interactions through BSCW in an intermediate subproject and in the final period where the final report was collaboratively written among four teams. The node shapes identify the different customers and the teacher. Line thickness is proportional to the number of interactions between two actors (BSCW).

This way, debating solutions make everyone know them and reinforces theoretical and practical knowledge [Quest – Final]."

Moreover, the structure of this final report is not provided by the teachers; therefore, students must decide on how to organize their ideas. This approach forces a discussion on how to write a technical report and shows an emergent result that is worth mentioning here. Some students decided to include an explicit section of comparison with other customers. Others used arguments that relate to other customers and technologies, as a means to discuss the business strategy of the consulting firm and the manufacturer they represent. In summary, they conclude that as consultants they have to be aware of available technologies, knowing their benefits and drawbacks, to better advise the customer. As manufacturers, they must know not only the technological alternatives but also the possible market sectors (i.e., the potential customers) to adapt their strategies. Thus, they see that this setting based on multiple case studies relates well to their future professional life.

However, a major drawback of this approach that students point out is an increased workload to cope with all the requirements of the project. Teachers have tried to reduce it by providing the mentioned templates for the reports and providing a selection of the information that could be read, though such action only slightly reduces the reality of the scenario. However, this large workload has an emergent positive impact: *students learn to plan in advance* and to accept that they depend on others for the goal achievement. This outcome can be seen from the increase in the use of collaborative tools toward the end of the course or by one student's statement to his interviewer: "we all accept that we must do each one's part, and we are responsible of the global work [Quest – SP2b]." Others state that they "have learned to coordinate in large work groups, though it has been hard [Quest – SP3b]."

The development of other skills, useful for the students' future professional life as stated by the IEEE/ACM Computing Curricula [4], has also been noticed. *Students learn to browse technical and commercial documentation*, to find useful information related to their problem, and *to write concise, well-structured technical reports*. In addition, *students learn to collaborate*, making and accepting reasonable criticisms and overcoming the competitive and individualistic culture in Spanish universities. When asked in questionnaires to define the class environment before the course [Quest – Initial], 37% said it was competitive; 50%, collaboration just with friends; and 23%, general collaboration. After the course, when asked again, the results [Quest – Final] were 25%, 34%, and 41%, respectively, indicating how their perception of collaboration changed after the whole experience. In addition, by the end of the semester, most of the students (70%) preferred participatory lectures over traditional ones, arguing more motivation to keep up to date with the course contents. Issues relating the evolution of collaboration are more deeply discussed in [20].

IV. Conclusion and Recommendations

This paper has presented an educational design for a computer architecture course at university level. Overall, the educational design addresses some of the open research issues on project-based learning, concerning intervention strategies that take into account institutional, curricular, and personal limitations [1].

The design presented is project based but consists of five different case studies developing at the same time by different teams of students. These case studies are similar in their methodology since they involve the design and evaluation of a computing system for a potential customer, but since customers are quite different, each team of students will focus on some particular needs and technologies to solve them.

Collaboration must be planned and strongly enforced so that each team of students gets somehow involved in others' case studies and, therefore, works with a broader set of concepts than those strictly required in their particular one. In this sense, this educational design included mandatory sections of comparison among customers in subproject reports and in the collaborative writing of the final report, supported by BSCW public workspace, and filling out forms through Quest, so that answers were made public and serve to set up public reviews, usually organized around apparent contradictions found in the answers.

A detailed, both quantitative and qualitative, evaluation carried out for four years showed that students generalize well their acquired knowledge to a new customer in the exam, even though it is quite different from the one they had during the course. Thus, it can be concluded that learning was deep, and it also covered the broad range of concepts imposed by the curriculum. In addition, the evaluation led to the conclusion that collaboration evolved during the course, and students' attitude toward it improved. Furthermore, a number of skills related to project-based learning and collaboration were reinforced, such as the ability to self-organize, plan, and share workloads or to write and read technical documentation.

After this experience, a number of recommendations could be applied to a similar educational setting. All of the case studies should be similar in their methodology and general objectives. This similarity provides students with a feeling of equality and induces a mutual interest by comparison and contrast of requirements and solutions. The case studies could be based on the teacher research interests, current trends in research or development, etc. This selection can have a motivating effect. It also provides different types of information sources that students can use to know their customer and the potential solutions, as in a real-world project.

Another recommendation is for the teacher to assume a role of knowledge facilitator rather than transmitter, i.e., not being prescriptive, inducing arguments with students, and reminding them of the importance of developing a methodology, not only learning concepts.

One practical issue concerns the excess of workload as compared to other traditional approaches. Obviously, project-based learning designs are more demanding both for the teachers and the students. If several case studies are used, as proposed in this paper, the workload can be slightly more than with a single case study. On one hand, students need to keep aware of others' projects, to enrich their vision. Collaboration tools can facilitate this task. On the other hand, teachers have to plan, document, and follow five different case studies. The estimation is that if case studies are inspired in their research, or the news from the general press or scientific magazines (and thus are partially understood by the teacher), one full-time day per case study is consumed at the beginning of the course for collecting and preparing documentation and thinking in advance of possible solutions and problems for that case.

The preparation of the debates held twice every subproject needs about half day each, separated into the preparation of the content questionnaires, collecting the answers, and organizing the debate. Special efforts must be paid to coordination if several teachers participate.

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