Tools and Strategies for Improving PBL Laboratory Courses with a High Student-to-Faculty Ratio

Javier Macías-Guarasa, Rubén San-Segundo, Juan M. Montero, Javier Ferreiros and Ricardo Córdoba
Department of Electronics Engineering. ETSI Telecomunicación (Universidad Politécnica de Madrid)
28040-Madrid – SPAIN {macias,lapiz,juancho,jfl,cordoba}@die.upm.es

Abstract - **Project-Based Learning (PBL) is one of the most interesting instructional strategies in the field of technical careers. However it is especially complex and difficult to implement when applied to laboratory courses with a high student-to-faculty ratio. In this paper, we describe our six-year experience of teaching laboratory courses in electronics in the Telecommunication Engineering Studies (a career that is a mixture of computer science and electronics engineering) after the adoption of the PBL philosophy, and the design and implementation of several strategies and tools to ease the administrative, teaching and learning tasks in these laboratories. Finally, we offer some evaluation results, showing that the adoption and combination of all our strategies and software tools actually works. Both the laboratory acceptance of the students (3.7 on a 1-5 scale) and students performance are high (they get 78.3% of the maximum grade, on average).**

Index Terms – Project-Based Learning; Administrative, teaching and learning tools; Instructional strategies; High student-to-faculty ratio.

INTRODUCTION

I. Project-Based Learning strategies in laboratory courses

"Project-Based learning" (PBL) [1] is one of the most interesting instructional strategies, mainly in the field of technical careers [2]. The PBL Strategy [3-4] aims at engaging students in authentic real-world tasks that enhance learning [5]. Students, typically organized in workgroups, face open-ended multidisciplinary projects with the instructor playing the role of facilitator or coach. Every team designs and implements a whole system with more than one possible approach, in an environment designed to simulate professional situations, where the students have to deal with different kinds of knowledge. This student-centered strategy fosters student initiative and other skills (apart from theoretical knowledge): time planning, resources management, assumption of responsibilities, negotiation and social abilities. This background is an important demand from companies and industry, as the Career Space Consortium remarks [6]. In this environment, the students learn the characteristics of each module and the interaction or interface between them, obtaining a global view of the system. This fact is very important for our laboratory courses in electronics, because we emphasize the idea that electronics is a fundamental

supporting technology for developing communication, control and signal processing systems.

II. Student-to-faculty ratio considerations

Although the student-to-faculty ratio in Spain dropped from 24 in 1998 to 17 in 2003 [7], we are still far from the low figures of other university systems such as the American one [8, 9]. Nevertheless, even in highly reputable university institutions with a low student-to-faculty ratio, one can find some high-ratio courses.

As an example, in our centre, the average ratio is 10.95, but in the two main laboratory courses in the third year, there are more than 400 students enrolled annually. The typical number of instructors assigned to these laboratories varies from 6 to 10, so that the average student-to-faculty ratio can be higher than 50 to 1. This number is manageable (and typical) in theoretical courses, where communication is mainly from lecturer to students. However, in PBL laboratories this ratio is overwhelming, as instructors have to deal with the specific problems of each team of students.

We consider a PBL course to have a high student-to-faculty ratio, if there are more than 15 workgroups per instructor. This situation makes effective teaching and learning a very difficult task, especially in practical courses with a PBL philosophy [10].

III. Paper structure

In this paper we first describe the courses on which we base our proposal. Then, the main section is devoted to giving details on the strategies and tools we have developed in order to improve the activities of our PBL laboratories, after which an evaluation section is included, with details on how the students perceive the courses and their course work performance. Finally, a section describing the main conclusions is given.

LABORATORIES DESCRIPTION

The courses addressed in this paper are the Laboratory of Electronic Circuits (LCEL) and the Laboratory of Digital Electronic Systems (LSED). Both are key compulsory courses in the curriculum of Telecommunication Engineers, taught in the 3rd year of a 5-years career, by faculty of the Electronics Engineering Department of Universidad Politécnica de Madrid (UPM).

Both LCEL and LSED are courses with a large student-to-faculty ratio, in which students, grouped in pairs. have to

design, build, test and document a complete electronic system. LCEL focuses on the design, assembly and measurement of electronic systems that include both analog and digital circuits. On the other hand, LSED introduces the students into the design, implementation and testing of microprocessor-based systems, in order to develop a prototype that combines both software programming (assembler and C) and analog and digital hardware.

Some examples of multidisciplinary assignments over the last few years have been:

- To design and implement a remote controller to switch on/off peripheral addressable systems, based on a coded serial communication bus and ASK analog transmission.

- To build an audio scrambling system that uses frequency inversion techniques with a dual carrier system and a digital LFSR control signal.

- To create an analog AM communication system including a digital subsystem for automatic channel search.

The specifications of the prototype to be built are open, encouraging the students to reach their own solutions and promoting their creativity and innovation (through which they can get higher grades).

STRATEGIES AND TOOLS

When we first applied the revised PBL philosophy in the academic year 1997/1998, we faced some difficulties because of the combination of the special characteristics of the PBL approach and the intensive student attendance (instructors have to deal with around 400 students every semester).

In this section we will describe these difficulties, along with the solutions we propose in terms of the design and implementation of specific tools and strategies. All the tools described have been implemented using free software supporting technologies, as they have proven to be extremely reliable and versatile; fulfilling all our expectations.

I. Administrative tools and strategies

Prior to our experience of renovating our laboratories (up to the 1996/1997 academic year), most of the administrative work was done manually by faculty. To reduce this high workload, we had to develop automation tools for:

- *Student enrolment*: Laboratory equipment and physical resources are limited and the allocation must take into account the restrictions imposed by the University, the students' schedules, and the availability of equipment. Full control of an automatic enrolment web-based procedure has helped us to evaluate the actual laboratory needs (for demanding more resources), and to establish flexible allocation policies for laboratories with different restrictions.

- *Laboratory slot occupation management*: By default, every team may attend the laboratory room once a week, but there are continuous student requests for extra slots in the laboratory, because of the open structure of our PBL approach: students seek higher grades through extra creative work. Our automated free-slot allocation system provides the students with fair access to laboratory resources, allowing requests within strict opening and closing times. In addition, the students must enter a random graphical access key in the web form (to avoid the use of automatic slot-requesting scripts) and there is a random delay for every received request (which avoids penalizing students with slow connection lines).

- *Examination planning and grading management*: examination planning must take into account several restrictions regarding hundreds of students: the timetable of both students and instructors, the different workloads of the faculty and, more importantly, that instructors must preferably examine students that attended their advising sessions (as they would be more familiar with the progress of those students). In order to automate the procedure, we designed and developed a specific allocation system, formulated as a search algorithm that makes intensive use of smart heuristics that ensure the generation of a close-to-optimal allocation policy within a given calendar period and the defined restrictions. In order to rank different allocation policies, we assign a certain cost related to their optimality, and to avoid local minima in the search, the algorithm iterates by starting from different random seeds and finally selects the best allocation scheme.

- *Student surveys management*: In Spain, universities carry out student surveys to assess their quality and to identify problems in the planning or in the teaching aspects. Students must fill in a form with questions regarding their experience in the laboratory and their opinion on the teaching abilities of the instructors. To avoid slow traditional offline surveys (prone to processing errors), we have developed an automated tool to design questionnaires in a flexible way. From this information, the system automatically generates: the required databases, a web-based form and a supporting tool for accessing the data and the processed statistical results, without any human intervention. Students access the survey application remotely, by entering a random key that guarantees both their anonymity and our security (to receive only one submission per authorized student).

II. Teaching and learning related tools and strategies

Dealing with an under-staffed PBL laboratory is not an easy task; instructors have to think in advance which strategies are efficient in handling teaching and learning activities, taking into account that they have such a large number of students. In small-scale laboratories this is not usually a big issue, as instructors manage a small number of working teams and their dedication to them can be quite intensive.

In the past few years we have designed and implemented a set of strategies and tools to be able to deal with our PBL laboratories efficiently:

- *Strategies for the design of efficient practical documentation*: The new PBL approach has increased the complexity of the laboratory assignment, so that the traditional stand-alone laboratory assignment document is

not enough in order to maximize student productivity. Our proposal involves:

- A *very detailed assignment document* (up to 50 pages), including a complete description of the theoretical foundations of the multidisciplinary problem to be solved, a proposed basic architecture, some implementation guidelines for specific subsystems and a tentative planning schedule that guides the students on how to organize their laboratory sessions to achieve the objectives in a professional manner, using a goal-oriented approach.
- A *textbook*, updated yearly and plenty of general information about practical details on the design, implementation and testing of electronic and software systems (not usually addressed in theoretical courses).
- A *Frequently Asked Questions* system, where the students can get information on practical issues closely related to the specific assignment of the course. The instructors update the FAQ on a daily basis, as needed, and the students can access it through the web throughout the laboratory sessions.

With these three sources of information, students are in a much better position to deal with their design and implementation issues efficiently during the system development process.

- *Strategies for the teaching sessions*: In spite of the detailed documentation provided, the complexity of the PBL assignment makes some lectures necessary (no matter how long the documentation). We have evaluated two approaches:
  - A detailed initial lecture: At the beginning of the course, instructors give a lecture that describes the whole system thoroughly (especially its mathematical basis).
  - Intermediate lectures: In every laboratory session, instructors give an initial brief lecture describing the main issues related to the subsystems that should be developed in this session, according to the proposed timetable.

In the first option, there is so much information to convey in the lecture, that students cannot assimilate it completely. In the second approach, the intermediate lectures face a synchronization problem: some of the students are delayed with respect to the planned schedule (so, for them, the lecture is too early) and some of students are ahead schedule (the lectures are late for them). This situation is dynamic and hard to avoid in PBL courses, so instructors need monitoring tools in order to choose the right moment for each lecture, the one that maximizes the number of students synchronized with the lecture.

So, our proposal is a combination of both approaches: an initial lecture focusing on the general aspects of the system that can make it easier to read the assignment document, and intermediate lectures synchronized with the *general* progress of the students and guided using the proposed schedule.

- *Strategies and tools for student progress monitoring*: A large number of enrolled students makes it more difficult to carry out a detailed progress monitoring of the course. In order to facilitate the progress monitoring process and to automate its analysis, we have designed and developed a tool for annotating the development stage the students have reached at any time. By comparing this information to the proposed timetable, the tool can detect major differences between current progress and the planned schedule. With the information gathered by the tool, we can estimate accurate statistics on the students' progress and identify possible problems in the planned schedule or unforeseeable difficulties in the laboratory assignment. The granularity of the reports is also adjustable, so that you can track the overall progress, specific workgroups or even selections of workgroups.

Another way of keeping track of the students' progress is by means of requesting intermediate progress reports from the students (which can include performance measurements, design schematics, source code, etc). In order to facilitate the reports management by instructors, we have developed a tool that allows the students to submit their reports remotely in electronic format, and, especially in the case of software-based laboratories (such as in LSED), these reports can be automatically analyzed to extract relevant information regarding the students' work quality. Intermediate reports are also useful for detecting students that cheat or plagiarize: students that plagiarize usually have an abnormal pattern of progress with one or several uncommon sudden advances in just one week (more on this issue below).

- *Strategies for guiding the advising sessions*: In a PBL course, advising students is probably the main task of the instructors. We can define two mayor instruction strategies: *polling* (the instructor talks to each team orderly on a one to one basis) and *interruption-based* (the instructor answers students' question as they arise). In PBL coursed with a high student-to-faculty ratio, the polling strategy has serious drawbacks: the instructors spend most of their advising time in polling and there is hardy no time for urgent questions. Because of the complexity of the system (different problems for different teams), if the instructor does not assist the students at these times, they may not able to succeed. In our proposal, and in order to optimize the use of instructors' time, we provide them with a daily report on every single team progress, so they can focus on advising students with slower progress first, and devoting the rest of their advising time to answer asynchronous questions. A final report (prior to the examinations) is also given to the instructors, in which students with low attendance that were able to complete the work are flagged, as they are suspected of cheating and a more careful examination will be advisable.

- *Strategies for efficient and exhaustive evaluation*: The work of students in PBL laboratories, because of its practical complex projects, it is rather difficult to grade. We may assume that the development of a fully working

prototype can guarantee that students have learnt the key points that make engineering projects successful However, as PBL is more a process than a final result, we must look at the process, not just the final system. All of our students are required to generate a complete written report on their work, and our evaluation proposal is based on two stages:

- Evaluation of the written report: the instructors evaluate the design strategy of each team and analyze the justification of the final design and implementation decisions, the calculation of component values, the design of inter-module interfaces, the project functionality, and the tests or measurements carried out.
- Evaluation in an oral examination, taking around 30 minutes per working team, for which we have defined an exhaustive protocol, including functionality tests, questions on obscure or ill-formed descriptions in the final report, general knowledge questions on main concepts acquired during the project, etc.

It is also important that the students know in advance what the evaluating criteria are, so they can focus on those aspects that instructors consider as the most important ones. In PBL courses it is not possible to define these criteria with a great precision from the very beginning, as the final functionality depends greatly on the students' initiative, and because the effort invested by the students in each module may differ from the initial instructors' estimation. Because of this, our proposal is initially publishing the broad criteria and, near the end of the course, and after a detailed analysis of the students' effort (partially possible because of the automatic tools developed), the instructors define the final criteria.

An important problem can also be found when several instructors (from 6 to 10), with different backgrounds, grade multidisciplinary projects: There is a risk of applying different grading criteria according to the background of the instructor. To avoid this, our proposal is the definition of an evaluation table that reflects the final criteria with a high level of granularity, in order to increase the objectivity of the evaluation process. The whole evaluation is ranged in a 0-100 point scale considering individual evaluation key points weighting between 1 and 5 points.

Finally, we have developed additional tools that generate overall reports and additional information that are useful for the instructor in charge of coordinating the laboratory courses.

- *Strategies for efficient electronic communication*: An adequate communication policy is of crucial importance in a laboratory with 400 students distributed in up to 10 weekly laboratory slots. Our experience shows that the use of an automated e-mail list system (linked to the student enrolment database), is much more efficient than the web-based forum strategy: most students read their e-mail every day, while a web-based forum imposes an additional effort.

- *Tools for plagiarism and cheating detection*: In courses with a large number of students, most of them have to develop the same basic system (instructors are not able to

specify and monitor different assignments for different teams) so that a certain degree of information sharing between students is not only admissible but also advisable. Nevertheless, students must achieve the educational objectives on their own, so most of the work must be based on original solutions. In our software based laboratories (such as LSED), we have developed automated tools to detect copies in the source code developed by students (standard similarity-detection programs are not useful as they are not fully adapted to dealing with assembly programs smartly modified by students). Given the high computational workload required to make full comparison among students we also use the monitoring data we collected (intermediate reports). By comparing successive files and routines from the same team, we can detect situations of sudden changes that are not usual in evolutionary prototyping. Although according to our experience, plagiarism is not high in a PBL (less than 5%), it is important to deter students from cheating (the rumor that plagiarism is easy can make PBL a failure).

- *Tools for automatic software quality analysis and feedback*: In the LSED course, the core of the project is the development of an assembler program on a Motorola microprocessor. We have also developed an automatic tool to analyze the style of an assembly program and to estimate its quality. This tool, based on statistical pattern recognition techniques, computes a feature vector with up to 48 basic characteristics from an assembler program. From the data collected in previous academic years (properly normalized to avoid differences resulting from the size of the program and the laboratory assignment that changes every year) we studied the correlation between the values of the features and the grade assigned by the instructors to the program (with the instructors being used as a source of *expert knowledge*). With this analysis, we obtained the relevance of each parameter regarding the grade and tuned an automatic tool that helps both the instructors and the students to evaluate the software quality throughout the semester. The automatic tool is also used to guide (feedback) the students. The instructors can get information on the quality of students' software and advise them not only in terms of the functionality they have achieved (as reported by the monitoring tools), but also in terms of the way they code it. The use of this tool has greatly improved the software quality statistics when compared to the previous academic years (e.g., the average number and length of routines or the use of complex addressing modes).

EVALUATION

I. Evaluation based on students' opinion on the course

When we adopted the new PBL philosophy, we decided to monitor different performance and quality metrics related to the students' perspective closely, using student surveys. In the evaluation shown below, among all the possible performance metrics we measured, we have chosen two of them as the most

appropriate, linked to the following two statements presented to our students:

- [Q1] The effort imposed by the course is worth it because of the amount of abilities and knowledge acquired: this roughly measures the ratio between two perceived variables, learning vs. effort required.
- [Q2] The course is a good one overall: it is a measure of the course overall perception, as perceived by the students.

To answer these questions, every student had to choose between five different answers with a numerical value: I fully agree (5), I agree (4), I partially agree (3), I disagree (2) and I fully disagree (1).

In Figure 1, we plot the evolution of the two performance metrics between the 1996/1997 academic year (in which we didn't apply the PBL strategy) and the 2002/2003 academic year. Regarding the effort worthiness [Q1], the students gave an average value of 3.4 maintaining a value higher than 3.0 since the 1997/1998 academic year. Considering the overall grading [Q2], the average value has been 3.7 and it has stayed above 3.5 since 1997/1998.
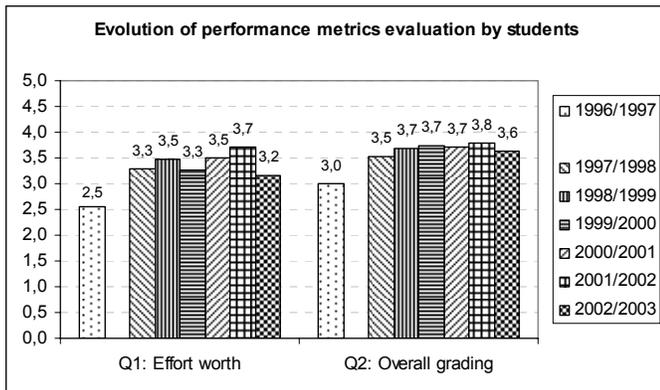

FIGURE 1.
EVALUATION OF THE LABORATORY COURSE FROM STUDENTS' SURVEYS.

If we observe the evolution of the two metrics carefully, we can see that [Q1] shows greater variations than [Q2]. The slight variations in the assignment complexity from year to year seem to be responsible for these variations in the students' opinion. Nevertheless, in spite of [Q1] fluctuations, [Q2] (overall grading) stays almost constant, around 3.7. This fact reveals that this parameter is not affected by the laboratory assignment and that we obtained a very good student overall perception throughout all the academic years in which the PBL strategies were applied (1997/1998 to 2002/2003). The relative improvement compared to the previous situation in the academic year 1996/1997 is as high as 34% in [Q1] and 22% in [Q2].

II. Evaluation of student's performance

During the past six academic years, we have been monitoring the grades of our students in order to evaluate their degree of achievement of the courses' objectives. As our detailed evaluation criteria is closely related to a measure of the

fulfillment of the course objectives, the higher the grades, the higher the degree of achievement.

Figure 2 shows, for example, the grading histogram in LCEL, aggregating data from 1997/1998 to 2002/2003. Our grades range from 0% to 100%, and students pass the course if they get 50% or more. Our data shows that during this period:

- Over 99.9% of our students passed the course.
- 55% of them got grades strictly over 80%.
- 9% got the highest possible grade (100%).
- The average grade was 78.3%, very high in our academic environment.

All these results show that even though the complexity of the assignments was high, the students were very successful in dealing with them and achieved the course objectives.
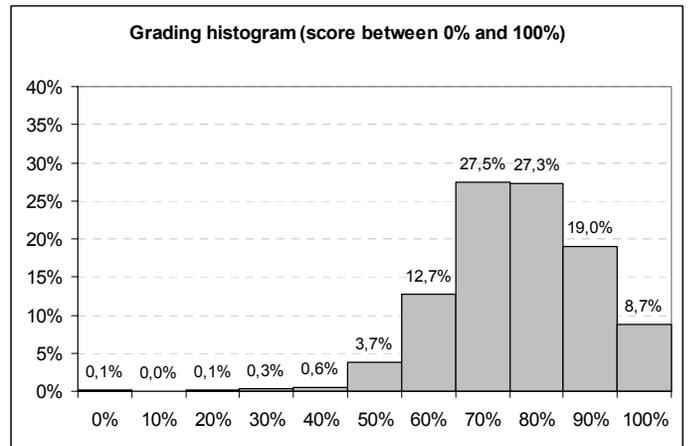

FIGURE 2.
ACCUMULATED HISTOGRAM OF GRADES FROM 1997/1998 TO 2002/2003

CONCLUSIONS

In this paper, we have presented a set of strategies and tools designed to face the problems when applying a PBL strategy in laboratories in electronics with a high student-to-faculty ratio. Our proposal has been the result of six academic year's experience, and the implementation, evaluation and tuning of every single strategy has been a costly process that needs at least one academic year.

The automatic web-based tools for enrolment and management have lead to a minimal involvement of the faculty in administrative issues, allowing them to concentrate on their teaching activities while improving student progress monitoring. Our strategies have been successful for designing efficient practical documentation, improving student progress advising, and defining an exhaustive evaluation process.

Laboratory slot-allocation management has been a crucial administrative problem, as the demand typically exceeded the available resources (because of the open nature of our PBL course and the students seeking higher grades through extra work). Our solution was tuned over several academic years by testing various strategies. Our final one ensures fairness by

means of a random access delay and a graphical access key, and it has received the highest consensus among students.

Regarding the teaching and learning strategies, an important conclusion is that the documentation and the teaching sessions must be carefully structured in order to guarantee the students assimilate the information provided. The assignment document is considered by the student as the main document. From this document, we must establish a set of structured links to the rest of the documentation resources (a text book, a FAQ system, the web pages, etc.).

We must also stress the tremendous importance of the progress monitoring tools and related strategies. Their success depends on student collaboration, because they have to state their progress status at the beginning of each laboratory slot. Although we were not initially optimistic about the student collaboration, over the past few courses we have verified that the students are collaborative if we show that this information is useful for helping them throughout the course: for example, for planning the advising sessions efficiently (a difficult task for a project-based course when the student-to-faculty ratio is high).

Our proposal regarding the evaluation task is a refined and well structured process, evolved over years of experience. The exhaustive evaluation combines a written report and an extensive oral examination. This mixed strategy ensures a proper management of the complexity in PBL courses (hard to obtain in written examinations), taking into account not only the final result, but also the full cycle of design-implement-test-document.

Additional strategies have been proposed in order to increase the objectivity and homogeneity when many instructors are involved in the grading process. Automatic tools for cheating detection and automatic software quality analysis are also fundamental modules leading to an efficient evaluation process. In this context, we can state that students do appreciate this objective grading process as a fair one.

The whole range of solutions proposed in this paper is a very good workbench where we can easily design and test ideas about different teaching strategies for PBL laboratories. These solutions have been evaluated and tuned throughout years. The evaluation of the laboratory courses shows that the suggested strategies and tools actually work in terms of student acceptance (on average, student grade the laboratories as 3.7 on a 1-5 scale) and in terms of student performance (on the average, they get almost 80% of the top grade). These figures show a remarkable success, especially if we take into account that our laboratory assignments are much more complex than assignments in standard guided laboratory courses.

REFERENCES

[1] Solomon, Gwen. "Project-Based Learning: a Primer". Technology and Learning, January 2003. Vol. 23. No. 6.

[2] Hedley, M.. "An undergraduate microcontroller systems laboratory." IEEE Transactions on Education, Vol. 41, No 4, Nov. 1998. pp. 345-353

[3] Markkanen, H., Donzellini and G., Ponta,. "NetPro: methodologies and tools for Project Based Learning in Internet," in Proc. ED-MEDIA 2001, World Conference on Educational Multimedia, Hypermedia & Telecommunications, pp. 1230-1235.

[4] Ponta, D., Donzellini, G. and Markkanen, H.. "NetPro: Network Based Project Learning in Internet," in Proc. of the European Symposium on Intelligent Technologies, Hybrid Systems and their implementation on Smart Adaptive Systems 2002, Albufeira, Portugal, pp.703-708.

[5] Ambrose S.A. and Amon, C.H. "Systematic design of a first-year mechanical engineering course at Carnegie-Mellon University" Journal Engineering Education, Volume 86, April 1997, pp. 173-182.

[6] Career Space Consortium. Online http://www.career-space.com/project_desc/index.htm [access March 2005]

[7] University Statistics from the Spanish Ministry of Education and Science. Online http://wwwn.mec.es/educa/jsp/plantilla.jsp?area=ccuniv&id=E123 [access March 2005].

[8] Stanford University Facts 2004 – The Stanford Undergraduate Program. Online http://www.stanford.edu/home/stanford/facts/undergraduate.html [access March 2005].

[9] Performance metrics at UC Berkeley. Online http://metrics.vcbf.berkeley.edu/ [access March 2005].

[10] Artigas Maestre, J. I. and Falcó Boudet, J. L. "Evaluación del aprendizaje de los alumnos en grupos numerosos: Una propuesta concreta". (Evaluating the students learning in courses with a high student-to-faculty ratio: A proposal) IV Congreso de Tecnologías Aplicadas a la Enseñanza de la Electrónica (IV Congress of Technologies applied to teaching electronics), Barcelona, Spain. September. 2000, pp. 59-62,.