Problem-based learning combined with project-based learning

a pilot application in Digital Signal Processing

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***Abstract*— The acronym PBL brings together two different teaching methods: problem-based learning and project-based learning. Problem-based learning methods focus on the acquisition of knowledge and are frequently used in the teaching of law and medicine. However, it is not common to find problem-based methods in use within the area of science, engineering and technology, where knowledge acquisition usually requires a certain hierarchical ordering of the contents. In the area of engineering, the predominant learning methods are clearly project based and tend to be directed towards applications of the knowledge acquired. Here a combination of the two strategies that permits the acquisition of knowledge through problem-based methods and the consolidation and application of that knowledge through project-based methods is presented. We then report on this combination of the two PBL methods as applied in the field of pattern recognition as part of a digital signal processing course within the Electronic Engineering and Telecommunications bachelor's degree at the University of Barcelona.**

Keywords—problem based learning, project based learning

I. INTRODUCTION

Progress in the fields of human knowledge and technology has been exponential over the last 50 years and this has led to a genuine social and economic revolution that has brought us into what is often referred to these days as a "knowledge society" or an "information society".

To a large extent, the task of training competent professionals in the area of science and technology, in order to meet the needs of society, is the responsibility of universities and related higher-education institutions. They have developed this task by following a traditional educational paradigm based on lectures which, in the best of cases, are accompanied by classes based on problem solving and guided practical sessions. This type of teaching has suffered from a slow but unstoppable process of alienation from the real needs of industry and society [1], [2], [3]. At present, being competent clearly includes having received a good scientific and technical training; but it also requires the capacity to adapt to the rapid changes and innovation that technological development bring about: the ability to constantly renew and recycle knowledge and communicative capabilities, and being adequately prepared to work productively in a group [3], [4].

The current social reality imposes conditions that make it absurd to think that knowledge can be reduced to a limited space and time. The speed of change, the sheer volume of technical knowledge available and the current tools for searching for information are effectively so powerful that they make delimited academic subjects seem dauntingly small.

It therefore seems clear that a change of paradigm is called for in the teaching and learning process. The method based on the one-way transmission of large quantities of knowledge is still useful because it allows fast transmission of information from an emitter (the lecturer or teacher) to multiple receivers (students) and because the student can benefit from the teacher's experience of the contents. However, it is a method with serious drawbacks: the students remember little of what they learn; the knowledge acquired is reduced to facts and data, but there is no reflection or criticism; and the relationships with other facts or circumstances and completely absent. All the students receive the same information, and learn in the same way and at the same rhythm; there is little room for innovation. Problem solving classes and practical sessions aim to overcome these shortcomings but often they just are not enough.

In order to integrate into higher education the capabilities needed to provide responses to the changing demands of society, a change of paradigm is necessary in the way we teach in general, and in the way we teach science and technology in particular. This change of paradigm must involve a shift to include the promotion of transversal competences (the capacity for teaching one's self and for group work, the ability to search for solutions to new problems, the capacity to rework knowledge and use it in new disciplines, etc.) that must accompany the technical knowledge in the different subjects and that provide the professional with the tools necessary to meet the demands of a highly dynamic setting [5], [6].

One of the tools that can best be adapted to these requirements is the so-called "problem-/project-based learning" (PBL). Here a PBL pilot application that was carried out in a subject within the field of engineering is reported.

II. PROBLEM-BASED AND PROJECT-BASED LEARNING

It is common to use the acronym PBL to refer to two learning techniques that are similar but not the same: problem-based learning and project-based learning. In order to distinguish them, the acronyms PrbBL will be used to refer to problem-based learning and PrjBL will be used for project-based learning.

As the name indicates, PrbBL is a teaching method in which the education process is focused fundamentally on the resolution of problems. At present, the definition covers

different practices that are not always comparable. It must be said, however, that notwithstanding the specific details of the organization of the teaching, PrbBL represents a working philosophy in which critical enquiry is the main action that guides the learning process. In accordance with this philosophy, the tutor must prepare a scenario that is suitable for the correct execution of the activity. This scenario can be presented in a wide variety of ways: as a text, an image, a sound file, a video, etc. It must always present a situation that contains a problem (if possible, a real one) and preferably the situation should not be very structured, but rather a generally open scenario, with a low level of specification [6]. In the analysis of this problem situation, the students must form hypotheses, discover learning requirements, organize goals, establish a work plan and carry out the enquiry that will lead to the target knowledge. Thus, the objective is not so much to resolve the problem situation as to acquire knowledge that can be generalized and to develop abilities and attitudes.

The PrbBL strategy has been implemented in different ways, which especially depend on the number of students [6], [7]. There are, however, certain common stages that can be observed in the process:

- Presentation and reading of the scenario
- Definition of the problem
- Brainstorming and devising a work plan
- Enquiry and research
- Summarising the results and extracting conclusions

As the students work through the stages, they become active and independent agents in the process; they critically assess what they read, plan tasks and develop the skills that will lead to meaningful learning. The tutor plays a key role in the process, as a facilitator. This includes: stimulating the students with questions; guiding discussions; helping the students to recognize and uncover both the problems and the knowledge they lack; focusing the debate on the main ideas; making sure that the students do not concentrate on inappropriate areas of learning or things they already know; offering assistance and advice; helping the group prepare work plans; encouraging the necessary commitment; offering a model of active listening; and encouraging productive attitudes [8], [9].

The PrbBL technique was devised in 1969 at the new School of Medicine at McMaster University in Canada. It has been used with considerable success in the teaching of law, economics, business studies and health science where “cases” can be presented in a relatively straightforward manner.

The success of the method soon led other centers, such as the new Limburg University in Maastricht or the Aalborg University in Denmark, to adopt it for technical education [10]. Since then, it has quite frequently been used in educational programmes for engineering, but it is far from being really consolidated in this field. Examples of its application have been documented in different degree courses and higher-education programmes in engineering [11], [12], [13], [14]; and it has also been used in technical education at levels prior to that of a degree in engineering [15], [16]. However, the reality is that the PrbBL method has made a much greater contribution to programmes in the areas of the health sciences and law than in science and technology. The vast majority of references to PBL in science, engineering and technology are associated with PrjBL [17], [18], [19], [20], [21].

Perrenet et al., [22] highlighted some reasons behind this difference, emphasizing that the structure of knowledge in the health sciences and law tends to be encyclopedic: the order in which knowledge is acquired or applied is not especially important. In contrast, the structure of the knowledge in science and technology is hierarchical: knowledge is built up in a certain order, based on prior knowledge. This may lead to a particular danger in PrbBL; given that the student is partially responsible for the learning process, and if the tutor does not guide and monitor the process correctly, then knowledge may be skipped or missed and this could result in important gaps later on that are difficult to remedy.

PrjBL, in contrast, is concerned with guiding the learning process through the search for a viable solution to a project. Wherever possible, it should: be based on real challenges; involve the students in research and the creation of knowledge; and be managed by the students. The objectives of PrjBL are really very similar to those of PrbBL. The main difference is that PrjBL focuses on the application of knowledge, while PrbBL focuses on the acquisition of knowledge. As it has been mentioned above, PrjBL has been widely applied in science and engineering degree courses and there are many references to it in the literature. However, given that they are usually referred to by the general term PBL, it is important not to confuse them with instances of PrbBL. The basic problem with the PrjBL method is that either the knowledge has been acquired previously, or the knowledge has to be acquired over the course of the project. Thus PrjBL is prone to the same problem as PrbBL is: there is a danger that basic knowledge is overlooked.

In order to reduce this danger as far as possible, the process that the students follow needs to be assessed in some way. Assessment certainly forms an integral part of all teaching processes. From the perspective of the traditional teaching paradigm, the student consumes information and the assessment aims to measure how much knowledge has been acquired. However, it is often the case that the assessment itself dominates the dynamics of the education process [23]. Within a PBL framework, the student generates knowledge and the assessment of the process should be based on evaluating the competences acquired in the processes of knowledge generation. One of the main difficulties in the process of assessing PBL (both for projects or problems) resides in the tools that are to be used. A standard exam is a reflection, sometimes a distorted one, of the technical knowledge acquired. It does not, however, usually reflect the learning process that each student has undergone, which may vary widely. Neither will it accurately represent the degree to which the student has acquired or improved transversal skills, values and attitudes. Furthermore, knowledge competences are not assessed in the same way as transversal skills and competences are. In order to evaluate knowledge and competences in

research and analysis, the assessment must necessarily depend on the tutor's observations of the student's activity and on the gathering of evidence. This evidence can be in the form of reports, presentations, open exams, tests, etc. The added difficulty with teaching based on PBL (problems or projects) is the issue of how to assess transversal skills, values and attitudes. In this case, again the tutor's observations play a fundamental role, despite the possibility of them being highly subjective.

Here, a contribution to the implementation of PBL based on combining PrbBL with PrjBL is presented. In PrbBL, a problem is presented which should lead the students to acquire new knowledge. During the PrbBL process, the students present evidence of learning in the form of reports and presentations and these form part of the assessment. Once the PrbBL concludes, a PrjBL process begins via a project in a field that is totally different from that presented in the PrbBL scenario. Over the course of the project, the students also present evidence of learning in the form of reports and through the presentation of their results. The combination of the two processes, PrbBL + PrjBL, has several advantages:

- It allows the acquisition of knowledge and competences to be assessed twice, thereby reducing subjectivity
- The PrjBL is based on knowledge acquired in the PrbBL process
- The PrjBL process provides additional assessment of the PrbBL
- PrjBL can compensate possible shortcomings generated in the process of PrbBL
- During the PrjBL, new competences develop, such as the capacity to reuse knowledge and apply it in new fields

The main problem in the implementation of a combined PrbBL + PrjBL approach is that it requires extra time. The specific pilot study and the results it generated are presented in the next section.

III. Pilot Study and Results

The Electronic Engineering and Telecommunications bachelor's degree at the University of Barcelona is a 4-year degree, organized into semesters. In order to be awarded the degree, the students must successfully complete 240 credits distributed over the 8 semesters (30 credits per semester). Digital Signal Processing is an optional 6-credit course, in the second semester of the fourth year. The course is organized into 3-hour sessions of theory plus 2 hours' practical work each week. The students who take this course have already completed: Mathematics Tools for Engineering, which introduce them to the tools used to process signals and continuous systems; and Signal and Information Processing, which introduces them to the tools used to work with discrete signals and systems. Since it is not a core course, the number of students is usually quite small, which allows PBL to be implanted easily.

The course syllabus includes contents on: identification of systems; design of digital filters; advanced tools for information processing, etc. In particular, the subject of pattern recognition has been chosen for the PBL pilot study that is reported here. The minimum and specific knowledge that the students should have acquired when they finish this course concerns:

- What a feature vector/pattern is
- The dimensionality issue
- Pre-processing of data (normalisation, outliers, …)
- What the selection/extraction of characteristics consists of
- Classification systems

The scenario that the students were presented with at the start of the course is the following:

> Juan and Maria, a couple of first-time parents, are at the end of their tether. Their little baby boy cries and cries non-stop, and they don't really know what to do. Watching over a baby who won't stop crying can be very stressful and what's more, a baby who can't sleep at night means parents who don't get any rest either.
> Unfortunately, finding out why their baby cries so much is no easy matter; it could be because he needs the presence of his mother, because he is hungry, because he needs his nappy changing, or in the worst case because he feels ill or has a temperature. If the baby is ill, they will want to find out and set off for A&E in a matter of minutes.
> A work colleague of Juan's told him about a device that can tell why your baby is crying. It is called the Baby Cry Interpreter.

The scenario is based on a real news story that appeared in both the printed press and on-line, and was about the crying of newborn babies (*La Vanguardia* 11/11/09: "El llanto de los bebés varía según la lengua materna", BBC News world edition: 15/10/2002, "Translating the baby's cry", available at: http://news.bbc.co.uk/2/hi/health/2329205.stm).

The "Baby Cry Interpreter" is a fictitious name so as not to advertise real products or brands, but it is true that there are devices on the market that claim to analyse babies' cries and some Apps have even been devised for iOS and Android. There are also references in learned journals and at scientific conferences to the analysis of babies' cries and their relation to certain pathologies [24], [25].

The PrbBL began with a class that included reading the scenario and critical analysis of it. In the process, attempts were made to discover what useful knowledge the students already had, a list of facts and target knowledge was drawn up, and the initial approaches to the research were agreed on. At the end of the class, all the ideas were summarised and tasks were assigned for the following class. The tutor was responsible for summarising the ideas and allotting the tasks, as agreed with the students. The initial tasks were principally

to search for information: patents, scientific papers and webpages dedicated to actual devices. The students found relevant references straight away which they read and presented to their classmates over the following two sessions. Over the remaining sessions, the research shifted from the specific methods that are usually employed in this type of devise (tonal analysis of the voice) to general knowledge regarding pattern recognition. The role of the tutor in this process was to guide the students' proposals, by providing advice and always encouraging the ideas that are most suitable for achieving the objectives of the syllabus, and offering alternatives to the literature searches. In the process, the students read relevant bibliographic material and prepared presentations for their classmates. The last class took the form of a class summary of the knowledge acquired together with a summary from the tutor of the target knowledge, and the objectives achieved. Ten hours were spent in theoretical sessions. The contents presented via the traditional method also covers a period of 9 or 10 sessions. All the initial cognitive objectives that emerged were studied during the course of the learning process. The students reviewed some of the basic algorithms used in the field, such as principal components analysis (PCA), linear discriminant analysis (LDA) and k-nearest neighbour (kNN) classification. Once the PrbBL phase had concluded, the PrjBL process began with the following aims:

- To consolidate the knowledge acquired in a highly practical way and in a scenario that is totally different from that of the initial presentation
- To test the students' capacity for abstraction and generalisation through applying their knowledge in a different scenario
- To assess the PrbBL process

In this case, the scenario is related to the analysis of data from a system for measuring carbon monoxide and oxygen in blood, based on absorption spectrophotometry. The dataset to be analyzed corresponds to optical absorption measurements of hemoglobin and came from a real project related to the development of a CO-oximeter by a medical instrument company. The dataset contains spectra from two types of hemoglobin: oxyhemoglobin (oxygen-saturated blood) and carboxyhemoglobin (carbon monoxide-saturated blood). For both types there are absorption measurements at increasing levels of saturation. The students are given a working environment based on MATLAB and PLS toolbox (Eigenvector Research http://www.eigenvector.com/software/pls_toolbox.htm) in which the pattern recognition algorithms already exist. The students were already competent to some degree in the use of MATLAB, and so they did not need to spend time learning to use the working environment. The goal was to find a pattern recognition model capable of distinguishing the two types of hemoglobin using the working environment provided correctly. The project was performed in the practical sessions of the course with the students working in pairs. They had 4 sessions of two hours each to complete the project. In the two first sessions, the students had to get to grips with the specific spectrum problem they had to deal with and carry out the preprocessing tasks they had learned. In the third and fourth sessions, the students applied the PCA algorithm and the kNN algorithm in order to generate a recognition model for the two types. All the pairs were able to use the tools suitably; they established useful and validated models correctly, according to the knowledge acquired in the PrbBL.

To close the learning process and with the aim of assessing it at a general level, the students completed a short questionnaire to evaluate their degree of satisfaction with the method. The most significant results are as follows.

In terms of their overall assessment of the experience, 100% of the students stated that the PBL method had helped them to learn the contents as well or better than a traditional method; nobody declare that the implementation of the contents in a traditional way would have been better that the PBL method. They also considered that this method resulted in knowledge that is more deeply seated than the traditional method, giving this aspect a score of 9.5 out of 10. The majority of the students (75%) consider that the effort they did is equal or less than they should be done under the traditional way. Additionally the students considered that the evaluation of the contents was adequate, giving to this aspect a score of 8.5 out of 10. From the point of view of the contents and acquired knowledge, all this assessments can be considered as positives and reinforce the use of the PBL method.

With respect to the skills that the method provides them with, the students stated that PBL:

- stimulated their critical and creative thought processes: 8.5 out of 10
- increased their capacity to work: 5.5 out of 10
- improved their communicative abilities: 6 out of 10
- allowed them to become more involved in the learning process: 9 out of 10

Also under the point of view of the skill, results can be considered as positives, and support the PBL method.

Finally, the students claimed to have worked for between 10 and 15 hours in addition to the hours spent in the classes and practical sessions. It is virtually impossible to measure precisely the work of the tutor in preparing the material for this pilot scheme, guide the students through the process and evaluate it. Neither was it possible to perform a comparative analysis with the process of teaching the contents in the traditional manner. In a subjective assessment, it was estimated that the demands on the tutor in terms of time were the same as or slightly more than those of preparing the material in the traditional way.

IV. Conclusions

This work presents a pilot PBL application as part of a digital signal processing course within the Electronic Engineering and Telecommunications degree at the University of Barcelona. The PBL application was divided into two parts: one based on PrbBL and the other on PrjBL. The pilot application did not cover the whole of the course, but only the

specific part of the contents that corresponds to signal processing for pattern recognition.

Combined learning based on a problem + a project allows the students' learning process to be followed and assessed more completely.

This pilot was a first PBL application and the students expressed satisfaction with the experience. The evaluation indicates that all the students assimilated the knowledge correctly.

It should be said that the students who took the course were already seasoned students who were about to finish their degree. In order to corroborate these positive results, it will be necessary to continue implementing the method and to accumulate experience in the same subject as a way of testing the repeatability of the process and, if possible, to implement the method in other subjects with less experienced students.

To extend the process into other subjects it is necessary to take into account the time required to implement PrbBL + PrjBL, and to look for ways to make the process compatible with the limitations of the academic calendar.

It is estimated here that the tutor spent the same amount of time on this application of the combined PrbBL + PrjBL method as on conventional teaching. It should be said that one of the most important points that generates most problems for tutors who follow a PBL approach is finding a real scenario that stimulates students to follow the process.

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