COMPUTER GRAPHICS *forum*

A PBL Experience in the Teaching of Computer Graphics

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Abstract

Project-Based Learning (PBL) is an educational strategy to improve student's learning capability that, in recent years, has had a progressive acceptance in undergraduate studies. This methodology is based on solving a problem or project in a student working group. In this way, PBL focuses on learning the necessary tools to correctly find a solution to given problems.

Since the learning initiative is transferred to the student, the PBL method promotes students own abilities. This allows a better assessment of the true workload that carries out the student in the subject. It follows that the methodology conforms to the guidelines of the Bologna document, which quantifies the student workload in a subject by means of the European credit transfer system (ECTS).

PBL is currently applied in undergraduate studies needing strong practical training such as medicine, nursing or law sciences. Although this is also the case in engineering studies, amazingly, few experiences have been reported. In this paper we propose to use PBL in the educational organization of the Computer Graphics subjects in the Computer Science degree.

Our PBL project focuses in the development of a C++ graphical environment based on the OpenGL libraries for visualization and handling of different graphical objects. The starting point is a basic skeleton that already includes lighting functions, perspective projection with mouse interaction to change the point of view and three predefined objects. Students have to complete this skeleton by adding their own functions to solve the project. A total number of 10 projects have been proposed and successfully solved. The exercises range from human face rendering to articulated objects, such as robot arms or puppets. In the present paper we extensively report the statement and educational objectives for two of the projects: solar system visualization and a chess game.

We report our earlier educational experience based on the standard classroom theoretical, problem and practice sessions and the reasons that motivated searching for other learning methods. We have mainly chosen PBL because it improves the student learning initiative. We have applied the PBL educational model since the beginning of the second semester. The student's feedback increases in his interest for the subject. We present a comparative study of the teachers' and students' workload between PBL and the classic teaching approach, which suggests that the workload increase in PBL is not as high as it seems.

Keywords: project-based learning, computer graphics education, Open GL, rendering techniques, computer animation techniques

1. Introduction

Problem-Based learning (PBL) is a learning strategy that encourages students to solve real problems organized in working groups. This methodology focuses on the student both as an individual and as a member of a working group and considers learning as a communication process [1].

In PBL, the problem or project is the milestone of the whole learning process. The project is the way in which students learn different skills. Usually, the project can have more than one solution. Students are in charge of their own advance and lecturers must provide the necessary tools to make this student work possible.

The problem or project proposed by the lecturer expects the student to achieve some learning objectives. PBL combines the advantages of the student's cooperation and the student's aptitudes in the same process.

1.1. PBL objectives

The objectives of the PBL methodology are [2]:

- Integration of knowledge and skills in different areas.
- Autonomy in the work and the learning.
- Teamwork.
- Self-assessment.
- Development of intellectual activities of a high level (analysis, synthesis and evaluation).
- Argumentation and critical reasoning.

1.2. PBL organization

PBL educational organization consists of suggesting a problem or a project to working groups of 5 to 12 students. In our case it is a project. The lecturer determines which topics from the subject schedule (Computer Graphics in our case) should be included in the project. Solving the project statement encourages debate, agreement and decision making within the group members: *What do we learn? What should we do?* The tutor (can be the same lecturer) carries out a periodic monitoring of the working group activity in classroom sessions of 1 or 2 hours, where the tutor can advise the working group and also observe the behaviour and roles that have been assumed by each of the students.

The role of the tutor is a central one [3] because he should encourage students to achieve the expected learning objectives without interfering with their own learning process. The goal of PBL is that students pose the problem and define a solution strategy by themselves. Only if the student deviates from the main learning objectives, should the tutor limit the student initiative and suggest other solution strategies.

The role of the tutor in the working group is [4]:

- Clarify the student's ideas. He should not impose his point of view, but identify any contradictions in the working group reasoning and request opinions from all members.
- Encourage the critical evaluation of ideas and knowledge.
- Facilitate discussion, through student interaction and exchange of ideas and experiences.
- Discuss strategies with the students, without making any decision, which is left to the student objective.

It is important to point out that in PBL the student's impression of the tutor's role changes: he is not an evaluator, but an advisor that helps to solve the problem. This change of mind results in a more friendly relation between tutor and students.

1.3. PBL evaluation

In PBL strategy we are not only evaluating knowledge, which is important in every learning process, but also the professional skills that the student has acquired during the learning process. Such skills are

- Teamwork.
- Abilities.
- Responsibilities assumed in the group.
- Criticism.
- Organization and manipulation of non-structured information.
- Critical thought, initiative and search for information.
- Oral communication and written skills.

The Bologna document about European university studies emphasizes the importance of these skills in university education.

The lecturer evaluates the student by means of technical reports and a slide presentation of the team work as well as the student's individual work and attitude during the supervised periodical meetings.

Self-evaluation, either of the whole group or individual, should also be considered. In the case of group self-evaluation, each member of the group must evaluate his mates in the group.

1.4. Why PBL?

Several points motivate following the PBL methodology:

- **Innovative reasons:** PBL promotes teamwork, student's self-initiative and information search. That means

that the lecturer is not the only source of information. Besides, PBL is not based on learning by heart learning, but knowledge is obtained by means of its comprehension.

- **Pedagogical reasons:** An increase in students interest in learning and research encourages them to use all the resources available.

- **Learning focused on the student:** The student is not a knowledge box, but an active agent in his learning and resolution of the project. He must learn to handle non-structured information coming from different sources (books, journals, Internet, etc.) and is encouraged to develop new ideas.

- **Conceptual value:** PBL enables interdisciplinary work which, although might imply not covering the whole subject schedule, suits to the current job requirements.

- **Not punitive but formative evaluation:** PBL philosophy is learning through student's mistakes, which removes the punitive feeling in failing from the evaluation stage.

1.5. PBL in universities

PBL is an educational methodology that began to be applied in medicine studies in the university of MacMaster (Canada). Since then, it has been progressively introduced in other universities and studies requiring strong professional training such as nursing or law degrees.

In Europe, the University of Maastrich is currently applying the methodology in law degrees [5] and offers every year a summer course addressed to people interested in PBL. Aalborg University (Denmark) [6] has definitively settled the PBL experience with the teaching of a master on PBL strategies and Brighton university holds a database storing the different universities, degrees and lectures currently using PBL at universities all over the world.

However, in engineering degrees and more precisely in Computer Science studies there are few experiences with this methodology, maybe due to the large number of students.

The only experience, to our knowledge, is Computer Science Technical degree (3 years) at the Politechnical University of Catalonia, in Castelldefels, which is completely based on this methodology. They have student groups of 25 in each subject.

To find other references of PBL, it is not very difficult to search in Google (www.google.com) typing 'PBL'.

In this paper we report our own PBL experience in the Computer Graphics for Computer Science Engineering studies. Since this is the first time we have tried PBL, we do not provide definitive results. However, we consider that it is worth reporting student's positive attitude to this new educational trend in university studies.

The paper is structured as follows: First, we explain the academic environment of the Computer Science degree and the Computer Graphics subject. In this section we also talk about the educational structure of the Computer Graphics subject before PBL application. Our PBL educational organization is presented. The next section is devoted to tutor effort time, with or without PBL and, finally, some preliminary conclusions obtained by tutors and students are discussed.

2. Academic Environment

Computer Graphics II is a subject taught in the third year (sixth semester) of the Computer Science degree. The degree is a 5-year study at the Engineering School (ETSE), of the Autonomous University of Barcelona (UAB).

The subject is an optional course of 60 hours, distributed in 30 hours of theoretical sessions, 15 hours of problem solving sessions and 15 hours of practice sessions in the computer lab.

Students must pass a compulsory previous course in Computer Graphics (Computer Graphics I) before registering. This previous course includes an overall revision of Computer Graphics: computer graphics input output devices, Computer Graphics 2D and 3D and some rendering algorithms. With this previous course, our students know the basic concepts of Computer Graphics.

Since Computer Graphics II is one of the optional subjects with more students (150) in the Computer Science degree, we propose to split students into two groups (with morning and afternoon sessions) of 75 students each.

2.1. Subject contents

The subject contents are focused on specific techniques for 3D Computer Graphics rendering and 3D Computer Animation techniques [7]:

1. 3D visualization (visualization and geometric transformations).
2. Rendering techniques introduction and antialiasing algorithms.
3. Solid modelling, spatial models, fractals.
4. Hidden surface detection.
5. Lighting. texturing, shadowing, ray tracing. radiosity.
6. Color.
7. Computer animation.
8. Morphing.

2.2. Subject organization without PBL

In the previous years the subject was scheduled in theoretical classroom sessions of 2 hours per week, based on the lecturer explanations using slides and software demos.

Figure 1: *Example of textured object truck built with GLU and GLUT graphic primitives.*

A weekly class was devoted to problem sessions (1 hour a week) based on explaining the OpenGL library and exercises on 3D objects building using GL, GLU and GLUT primitives and OpenGL geometrical transforms (translate, scale and rotate). Figure 1 shows the suggested exercises: A truck with BMP textures.

In addition, some exercises of articulated objects (robot arms, human legs, etc.) and arms motion are carried out, articulated legs, etc. by means of code OpenGL are suggested to students. These exercises can be easily validated in the graphical software environment available to work in practice sessions.

The practical sessions consist of four practices distributed in 6 sessions of 2 : 5 hours. These practices are carried out on a graphic software environment that uses the OpenGL library. It is basically a drop-down menu application and has a set of basic menu options already implemented (Figure 2). This graphical environment can be downloaded from Computer Graphics II web site (`upiia.uab.es/teach/a25011/c25011.htm`). The graphical application has the following options:

- Point of View (*Vista* at Figure 2): The camera position (point of view) is defined in spherical coordinates (R, α, β) and moved in interactive form by means of the mouse device. The mouse left button controls the angles α, β and the right mouse button controls the zoom R.

- Projections type (*Projecció* at Figure 2): The perspective projection with the interactive point of view motion is already implemented.

- Objects rendered (*Objecte* at Figure 2): A pop-up menu allows switching between three OpenGL basic primitive objects: a cube, a sphere and a teapot, all of them size 5 in world coordinates. The objects are centered by default at the origin of world coordinates. Students are expected to add new objects (built from OpenGL primitives) to the Object Menu.

- Hidden surface (*Ocultacions* at Figure 2): Options of back face culling and z-buffer are implemented and these options work. All these options are disabled by default.

- Lighting (*Il.luminació* at Figure 2): The three types of lighting that offer OpenGL can be selected: wire, flat lighting and smooth lighting (Gouraud shading) are implemented and they work. The default value is wire.

In order to view a 3D scene one should select a value for projection and object. By changing menu options the user can visualize different scenes.

Each practical work must be incorporated in the graphical environment. The final presentation requires presentation of a unique graphical environment with all the practices included.

The first two practices are oriented to the acquisition of basic skills and knowledge and require implementation of the
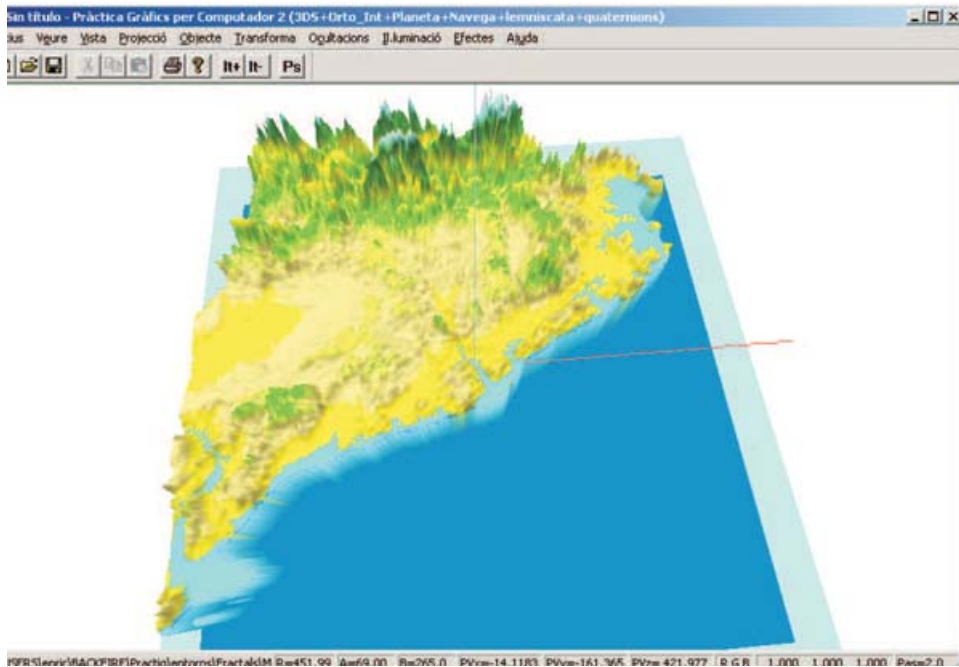
Figure 2: *Menu options of graphical environment: Files (Arxius), Viewing (Vista), Projection (*Projecció*), Object (*Objecte*), Geometric Transforms (*Transforma*), Hidden surfaces (*Ocultacions*), Lighting (*Il.luminació*), Other effects (*Efectes*) and Help (*Ajuda*).*

ortographic projection and building different objects (ships, airplanes, etc.) from primitive graphics.

The last two practices focus on computer animation, including rigid object motion, movement along given trajectories (motion of an airplane or a ship on a landscape fractal terrain) and articulated motion (robot arm with two articulations and six angles of turn and leg with two articulations and three angles of turn) by means of the definition of two or more key frames. Another practice consists of the implementation of a game (the Hanoi towers). Every year we choose two of them. In all these practices we give the students a statement containing the main requirements of the work to be developed and an EXE file demo. The demo application serves to show the student what the final result should be.

Currently we have the following versions of the environment: Visual C++ versions with MFC in one-window and multi-window application in Windows, a version with GLUT interface in Windows, a Linux version and in this year the MacIntosh in C++ and Java in Windows versions are being implemented, all these graphical environments include OpenGL graphical library.

At the Computer Graphics II web page (upiia.uab.es/teach/a25011/c25011.htm, in Catalan), all the material is available to the students. The given resources include theoretical sessions slides, OpenGL notes, practice

statements, graphic environments, different exams solved in early years and computer graphics links of interest for the students. All this material is given at the beginning of course.

The evaluation of the subject was carried out by means of an exam given at the end of the semester. This exam is 60% of the final evaluation and the delivery and defense of the practices 40% of evaluation.

After many years of giving these topics to the students within the standard teaching methodologies we have reached the following conclusions:

• The student's attendance in classroom theoretical sessions significantly decreases along the course. Lack of student attendance is more significant in morning sessions. Documentation availability on Internet is an important source of class absenteeism. However, documentation availability encourages really interested students in the subject to assist in the classroom sessions and avoids assisting students who are not really interested.

• Problem sessions also suffer from student absenteeism although the attendance in these sessions is higher than theoretical sessions.

• Lab. sessions attendance rate is the highest. The practices work is presented at the required deadline and it

is usual to find applications with extra resources: more complex objects, OpenGL advanced options of OpenGL implemented, etc. This proves that the high interest is in practical applications, at least for a important minority of our students.

- There are some students who show a high interest in Computer Graphics topics and ask for postgraduate continuation in the area. We must keep in mind that, although the subject is optional, a great number of students choose it and show even more interest than in compulsory subjects. Every year there are some students who give some interesting code, set of functions, etc. that enrich the graphical environment set.

The previous considerations motivated searching for strategies encouraging students in Computer Graphics topics and OpenGL-based environments. The chosen methodology was PBL.

However, PBL is a time-consuming strategy that requires the lecturer to prepare projects and materials and an additional dedication to advise the working groups to the right way if necessary. Besides, it is not well suited for large (more than 100) groups.

Taking into account that not all students registered in the subject show the same interest and that they have different profiles, we have decided to offer them two different schedules

- Classical learning: Itinerary based on theory, problems and practice classroom sessions, with exam evaluation and practice work presentation.
- PBL: PBL Itinerary, which we detail next.

3. PBL Itinerary

In our case, the project will consist of the implementation of a computer application based on the graphic environment offered on our web site (actually Visual C++ application with OpenGL with MFC or GLUT under Windows or Linux).

Working groups consist of 4 to 6 students who normally have already worked together. In the first session a short (6-10 lines) project statement is given to the working group. During the first meeting the group must discuss the following important points:

1. *What we know, what we need to know, where to seek the information that we do not know, who makes the search.*
2. *What functionalities we want in our application for the project?* The students must decide the complexity that they want to undertake to solve the problem.

Once every 15 days and in theoretical sessions, the working groups gather together to discuss with the tutor ideas and task distribution. A meeting record summarizing people's assistance and the working group activity (ideas, agreements, etc.) is written down and given to the tutor.

Each working group has a supervised meeting in the earlier theoretical classroom sessions (2 hours) every 15 days. In each session we admit a maximum of five working groups with 4 or 5 students each. That means a maximum of 25 students. We have two sessions (morning, evening). Taking into account that every working group has a meeting every 15 days we have $2 + 2$ theoretical sessions with different working groups. That means we can offer the PBL process to a maximum of 100 students from the 150 that are registered.

Apart from guided lessons, working groups should meet on their own initiative and report any advances and agreements achieved.

Also, we suggest to the working group to attend the problem classroom sessions to acquire certain theoretical know-how and carry out OpenGL exercises that can be useful to them in the development of their project.

These students should not do the practice work. Nevertheless, they can attend in practice laboratory sessions optionally to carry out their project, guided by a lecturer.

3.1. Project examples

The projects suggested by the lecturers intend to cover 60% or 70% of the subject content. Next, we show some examples of the projects suggested to our students with an abstract of the educational objectives.

3.1.1. *Project 1: Solar system*

Statement:

The IEEE (Catalan Space Studies Institute) wants a graphic viewing tool that allows to see with certain degree of realism, as much as possible, the position of the main planets and satellites of the Solar System as well as their motion, so that the position of the planets and satellites can be seen on a specific date (day-month-year) and at a specific hour (hour-minute-second).

Learning objectives: We try to make the students learn and work with topics of the subject contents:

3D Visualization: Coordinate system to represent the Solar System. Geometric transformations to position each planet and satellite. Definition of different points of view (on planets or satellites).

Modelling: To define the data structure to represent the planet positions. Use of OpenGL primitives to draw planets, planet rings, etc.

Lighting: Light sources definition (Sun), textures (planets and satellite surfaces), shadows.

Motion: Definition of paths (belonging to planets or satellites), implementation of planet motion, to find the planet or satellite position on a specific day and hour. Interaction with the movement: stop and activation, forward and backward.

3.1.2. *Project 2: Chess*

Statement:

The Catalonian Chess Federation hires you to carry out a graphic application that allows the visualization, as much as possible, of a chess game. We want to see the chess game like a movie: in a continuous play sequence or playing step by step, forward or backward.

Learning objectives:

3D Visualization: Definition of the chess board and the coordinates of each square of the board. Definition of points of view to see the board.

Modelling: To create the chess pieces and the data structure to define a configuration of chess pieces on the board.

Lighting: Lighting of the scene, textures (chess pieces, board), shadows, collision detection when you make a movement.

3.2. ABP evaluation

In this itinerary the student neither needs to take an exam nor practical tasks as the evaluation of the subject under PBL is project based.

In the last theoretical classroom session of the semester (last week of May) the working group must present their project. Project presentation includes the following documentation:

Student Portfolio: Summary of the work carried out by the working group. It must include the project statement chosen by the group, objectives planned to solve the project, development of their work and conclusions of the work carried out as well as any improvements if possible. It should also include all meeting records (guided or not by the tutor) and a user's manual and a reference (variables and functions) of their application. A portfolio model of documentation is provided in the subject web site, with an index of the contents.

Computer Application: Computer application made by the working group as solution to the project statement. The user's manual and reference manual must be included in the portfolio.

Presentation: Brief slide presentation that a member of the working group should make in oral form to the lecturer

Table 1: *Student time workload (in hours) in the classical itinerary of 13 weeks. Prof. = Hours with professor, Al. = Hours of autonomous study, Exa. = Hours to prepare the exam, Teo = Theory, Pbl. : Problems, Prc. = Practice.*

	Prof.	Al.	Exa.	TOTAL
T.	$2 \times 13 = 26$ hours	$2 \times 13 = 26$ hours	12 hours	64 hours
Pbl.	$1 \times 13 = 26$ hours	$1 \times 13 = 26$ hours	6 hours	32 hours
Prc.	$2.5 \times 6 = 15$ hours	$5 \times 6 = 30$ hours		45 hours
			Total:	141 hours
			ECTS:	5.6

and to other students. A model of documentation presentation is provided in the subject web site, with an index and comments on what there should be in each slide.

The lecturer evaluates with this information the knowledge acquired by the working group, and also some important skills as oral and slide presentation, portfolio presentation, etc. that are demonstrated.

4. Student Workload

In this section we calculate the student time effort values for each of the two itineraries.

4.1. Student workload in the classical itinerary

The educational requirements of the subject in credits are 3 of theory, 1.5 of problems and 1.5 of practices. According to that in the classical itinerary (theory, problems, practices and exam) the student workload during 13 weeks is shown in Table 1.

This educational load takes into account an hour of additional study without the lecturer for each hour of theory classroom hour or problem classroom hour, both lecturer guided. In practice sessions we take into account 1.5 hour of additional study for each hour of practice classroom guided by the lecturer.

These 141 hours divided by the 15 weeks of the semester (including exams) give a student dedication in our subject of 9.4 hours for a week.

4.2. Student workload in PBL itinerary

In the PBL itinerary, the classroom sessions guided by the tutor are delayed 15 days and they are compulsory. The problem classroom sessions are optional for the working groups, but it is recommended that they attendence of them. About the practice sessions we recommended to attend the first session of practices to work and know the graphical OpenGL

Table 2: *Student time workload (in hours) in PBL itinerary of 13 weeks. Prof. = Hours with professor, Al. = Hours of autonomous study, Doc. = Hours to prepare documentation (portfolio and slides), T. = Theory, Pbl. = Problems.*

	Prof.	Al.	Doc.	TOTAL
T.	$(2 \times 7 = 14) + 10$	$3 \times 13 = 39$	$1 \times 13 = 13$	76 hours
Pbl.	$1 \times 13 = 26$	$1 \times 13 = 26$		26 hours
			Total:	102 hours
			ECTS:	4.08

Table 3: *Work capacity in student groups of 4 and 5 members.*

No. of students	Total hours	No. of hours/week
4	$50 + 4 \times (39 + 13) = 258.$	$3.8 + 4 \times (3 + 1) = 19.8$
5	$50 + 5 \times (39 + 13) = 310$	$3.8 + 5 \times (3 + 1) = 23.8$

environment. The other practice sessions can be used to work in the project. Keeping in mind these recommendations, the estimation of the effort of the student in this educational modality is shown in the Table 2.

These 102 hours divided by 13 weeks (in this case the time of exam is not taken into account) give us a dedication of 7 to 8 hours/week, keeping in mind that the 10 hours additional of classroom sessions are practice sessions that can be used.

There are two important differences between both tables and methodologies. First, the time workload in PBL methodology is concentrated on the project. Second, the calculation of Table 2 corresponds to the hours invested by the student, so that a group of 4 or 5 people dedicates some fixed hours with tutor, but the hours of autonomous work can be multiplied for the number of members of the working group since we accept and encourage each member of the group to carry out different tasks. This means a capacity of work that is shown in the Table 3.

All these calculations give us the approximate work capacity of the group. This capacity can influence the degree of complexity decided by the working group.

5. Lecturer or Tutor Workload

Since the course has not yet been completed, we do not have definitive conclusions on the lecturer or tutor workload in our PBL experience. On the one hand, it is evident that PBL increases the tutoring task on the students and this task is very different from giving theoretical classes. But, on the other hand, this tutoring effort is a time saving in exams and practical work evaluation.

This educational organization allows the theory and problem lecturer to concentrate on the theoretical and problem classroom sessions in 1 hour a week, since the other 2 hours are devoted to advising the projects.

All subject documentation (transparencies of theory and problems) is available from the first day on the web site. That means that students have this information available, to read it or not, but the lecturer can explain a brief summary of each topic emphasizing the more important concepts of each topic without the need to enter into detail. This detail great is already available in slides and books. The student can always ask any doubts to the lecturer when he has not understood a topic.

We think that the educational load time of the lecturer taking into account the number of sessions and hours does not change meaningfully. The educational quality of these hours become more profitable for the students. The only additional work, of advising the working groups during the semester is saved because students do not attend any exam at the end of the course.

6. Results

Last year, a pilot test of this methodology in two working groups of 4 people each was carried on. The result was different in each working group. The first group finished the whole proposed exercise and their degree of satisfaction with the methodology was high. Due to personal problems the other group could not reach the expected objectives but they were very interested in finishing it.

From that first experience in the PBL itinerary we decided to offer it to the students as an alternative to classical learning methodology based in theoretical lessons, and problem and practice work.

The result has been that a total of 70 students (from 150 registered students) distributed in 16 working groups have chosen the PBL itinerary. Of these 65 students, six have already swapped to the classical learning approach.

From the lecturer's point of view, theoretical lessons stop being a monotonous replay with no more content updates. The advisore's role in PBL represents a more dynamic and exciting job, which even gives the chance of learning from student initiatives. The latter improves students' opinion about the tutor and the lecturer.

However, this methodology cannot be fully applied to all subjects or years in university studies. But PBL suggests an alternative learning method and the lecturer must decide if PBL can be applied in their subject and the level of its application.

7. Conclusions

In this paper an organization of Computer Graphics that offers two learning itineraries is reported. The student must choose between the classical theory, problems and practices schedule based on an exam and an itinerary based on the PBL principles.

A set of projects fulfilling some educational objectives related to the subject is suggested. Also, PBL allows evaluation of some professional aptitudes, which are very important for student education.

From 150 students registered in our Computer Graphics course, 65 students have chosen the PBL itinerary. This means 43% of the total are in the first year of application.

Although we do not have definitive results yet (we hope to have them in July) the first PBL meetings show a promising degree of acceptance and interest in the proposed PBL itinerary among students interested in Computer Graphics who have chosen this learning methodology.

We are aware that we teach an attractive subject to the students (the results are spectacular) and that Computer Graphics is a subject with a strong presence in movies, television and video games. The latter is an extra motivation to promote the subject more and adopt an educational methodology that allows improvement of student interest and initiative in computer graphics topics.

We have as yet decided to maintain the classical itinerary, being conscious that students are not all equals and that it was necessary to respect the plurality of student profiles and also to be sensitive to the different degrees of interest that we can in our students. We believe that this double itinerary offers greater flexibility for studying a subject. A certain responsibility is transferred to our students because they can establish the quality of their learning and the professional aptitudes they want to develop in the Computer Graphics area.

As a result of this first experience, we expect to obtain conclusions and to evaluate weak and strong points of work carried out to improve in content and the learning quality in the university education that we want to carry out.

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