PRINCIPIA PROGRAM: EXPERIENCES OF A COURSE WITH INTEGRATED CURRICULUM, TEAMWORK ENVIRONMENT AND TECHNOLOGY USED AS TOOL FOR LEARNING

Francisco DELGADO
Mathematics Department, Tecnológico de Monterrey (ITESM), Campus Estado de México.
Carretera a lago de Guadalupe Km. 3.5, Col. Margarita Maza, Atizapán, Edo. de México, México.
e-mail: fdelgado@campus.cem.itesm.mx

Rubén D. SANTIAGO
Mathematics Department, Tecnológico de Monterrey (ITESM), Campus Estado de México.
Carretera a lago de Guadalupe Km. 3.5, Col. Margarita Maza, Atizapán, Edo. de México, México.
e-mail: rsantiag@campus.cem.itesm.mx

Carlos PRADO
Mathematics Department, Tecnológico de Monterrey (ITESM), Campus Estado de México.
Carretera a lago de Guadalupe Km. 3.5, Col. Margarita Maza, Atizapán, Edo. de México, México.
e-mail: cprado@campus.cem.itesm.mx

ABSTRACT

The ITESM's teaching model has evolved in the last few years. Nowadays, several abilities, attitudes and values (AAV's) are taken into account without forgetting the development of knowledge in students. These AAV's include teamwork, the use of technology as a tool for learning, self-learning, problem solving, among others.

Within this evolution process, several problems were identified in the former model used at ITESM to teach mathematics and engineering. These problems involved both teachers and students. For instance, there was poor knowledge retention in students, courses were too centered on algebra instead of developing mathematical reasoning and rules and algorithms were preferred to practical applications in the areas students are usually interested.

"Principia" is an engineering academic program which comes out from the idea of overcoming those difficulties. The main purpose of Principia is to develop a mathematical, physical and technological culture in students that will make them able to analyze and solve complex problems. This is achieved with the integration of different subjects in one unique program where the classroom and learning environment are considered.

"Principia" has been planned and implemented for the four first semesters of engineering. Some of the basic tools used in this program are problem based learning (PBL) and heavy use of computer technology. There are five fundamental principles in "Principia":

a) Integration of the curriculum for mathematics, physics, and computer sciences.
b) Collaborative learning.
c) Teamwork.
d) Emphasis on mathematical modeling.
e) Use of technology in the learning process.

With all these elements, "Principia" has evolved as an integrated program that considers objectives, knowledge, methodology and an evaluation system. In this paper, we share our experiences in "Principia" over three generations of students and some statistical and comparative results.

Keywords: curricula, innovation, technology.

1. Background

In the last years, a change in the ITESM's teaching model has been observed. Under these new ITESM teaching model, in addition to knowledge, development of some abilities, attitudes and values (AAV's) is being taken into account. In the past five years, the Math Department has developed different projects in which the following AAV's are being emphasized: use of technology in every math class and going in pursuit of students learning. Some problems in math teaching and learning in teachers and students have been identified thanks to these projects. "Principia" program comes out from the idea of overcoming these problems, looking forward to improve the teaching and to enlarge the learning spectrum of students from different areas of engineering. Besides, it considers the classroom and the environment where this learning process takes place and it introduces an educational strategy in mathematics, physics and computer science that leads to the development of the AAV's stated in the ITESM's mission. Some of the most important characteristics and methodology of "Principia" are included in this document.

2. "Principia" program

"Principia" program is a teaching-learning model of basic sciences aided by technology, which fosters the use of abilities for teamwork, self-learning, creativity, analysis and synthesis of information in engineering students, in agreement with the objectives of the ITESM mission. "Principia" is based on the following fundamental principles:

a) Integration of mathematics, physics, and computer science courses curricula .
b) Collaborative learning.
c) Teamwork.
d) Mathematical modeling as a fundamental tool for sciences and engineering.
e) Use of technology in the learning process.

The objectives and principles of "Principia" were stated as a result of research on the deficiencies of the teaching model in the area of mathematics and basic sciences in engineering. Having identified these deficiencies in teaching and evaluation of concepts learned, new alternatives experimented in the teaching environment are being researched. As a consequence, those elements and methodologies that have been successful in the development of AAV's were then selected. Design of physical spaces and technology that affect this process were also considered. Several activities which constitute operative and methodological design are used to follow these principles:

- Field of study
- Lectures
- Exercises solving
- Laboratory
- Presentations
- Subject Evaluation
- Problem based learning (PBL)
- Project oriented learning (POL)
- Learning based on technology (LBT)
- Exams with integrated curriculum (EIC)

The first six correspond to the classical activities in the classroom. The last four have been introduced in “Principia” taking up to 50% of the effective time of the program as basic elements in its structure.

3. Curricular integration

Curricular integration is not an isolated issue, different experiences have been carried out [1, 2, 3]. In “Principia”, curricular integration is, of the five principles, the moving axis of activities, while the following four are the means to reach the objective. To achieve curricular integration in “Principia” entailed introducing additional activities that required more time. This had to be reduced as much as possible to achieve a balance with its former antecessor scheme. Therefore, PBL, POL, LBT and EIC allowed us to:

a) Consider the content of all integrated areas and long term objectives.

b) Take advantage of recurrent contents to achieve meaningful learning.

Table 1 shows the basic topics for each semester of “Principia”, under the scheme of integrated curricula [1].

4. Collaborative environment and use of technology

1) The use of collaborative techniques and technology in learning and the classroom.

Table 2 shows some aspects and desired objectives. We must point out the fact that the design of space (classrooms equipped with complementary facilities) comes out in a natural way when considering the processes that occur in our activities. Each classroom is a room with movable divisions. It has 10 tables for teamwork that allow connection to Internet. Additionally there are working zones and library space.

The curriculum integration is based on PBL and POL methodologies. The first one allows progress in all areas, working on their specific goals. In the second we integrate all areas.

2) Problem Based Learning (PBL)

Collaborative learning among students is developed in the program in several activities:

a) Exercises solving, where students leave their basic team to form new heterogeneous teams to solve excercises of academic nature. The objective is to develop elemental level and to return to the original teams to share and to enrich the knowledge of their team members.

b) PBL that in its design integrate some of the organization of the exercises solving, to identify and to solve a more real and complex situation, normally with integrated curriculum. In “Principia”, commonly this activity requires the use of technology for its development.

c) Development of projects is the open solution of a complex situation which involves the acquisition of additional formal knowledge. In these projects, future knowledge of the field of students is concerned.

[1] This curricula comes as a result of the integrated program. The traditional curricula is not as long.

Of these, PBL is the most recurrent and the most useful activity in “Principia” to develop its principles. Since beginning of PBL as a formal paradigm in medical education at Mc Master University [4, 5], several other universities have adopted this educational practice in various countries [6] and inclusively in some areas of Engineering [7, 8], as also in levels of basic education [9, 10], and high school [11, 12, 13, 14].

In the PBL approach, students are confronted with complex, usually multidisciplinary problems, which must be solved in teams. Problems should be sufficiently complex that students' prior knowledge and conceptual frameworks become insufficient to solve them. So, during the initial discussions the problems should trigger the questions that guide student’s search for information and self-directed learning. Under these conditions, learning is guided by the students’ questions.

Generally, the PBL curriculum is organized around general themes, instead of the discipline-based organization that characterizes the more traditional curricula. This kind of organization requires teams of teachers with different disciplinary backgrounds to prepare activities. Here, some general principles that guide most PBL educational practices may be summarized in didactic principles and professional orientation principles [15].

The didactic principles may be summed up as follows: First, the instructor may facilitate the process, but students must become responsible for their own learning. Secondly, knowledge and skills acquisition is a process that require students’ active participation. Lecturing and other “transmission of knowledge” approaches are of little value under PBL. Third, students are oriented to cooperative work rather than to competition.

With regard to professional orientation: professional practice is seen from a holistic point of view. As was mentioned before, instead of the specialized disciplinary organization that characterizes traditional education, PBL arranges contents around multidisciplinary issues. Therefore, PBL aims to generate an integrated learning process. This integration is twofold. On the one hand, students should integrate knowledge from different domains. On the other hand, PBL should help students to integrate knowledge with skills and abilities.

As Douady[16] states, “For a teacher, ‘teaching’ refers to the creation of the conditions that will produce the acquirement of knowledge by students. For a student, ‘learning’ means to get involved on an intellectual activity where the final consequence is the availability of a knowledge in its double status of tool and object”. This idea allows us to understand the complexity of an ideal teaching-learning process. Additional to knowledge, there are other elements that participate in the process. In this sense we can say that this process is multidimensional, knowledge being just one of the dimensions.

Beyond Polya’s ideas [17], PBL takes us to the consideration of elements that are present either as the natural part of a mathematics problem or related to the solving processes involved. The common problem solving design elements normally include [18, 19, 20, 21]:

- Objectives
- Requirements
- Material
- Instrumentation
- Discussion outline
- Evaluation

Furthermore, some authors consider these aspects in the itself problem level. They mention that there is a second level that corresponds to the environment of the problem [22] and summarize the consideration of this level in four principles:

a) Goal of the activity can or cannot be accomplished by the students.

b) Problems can modify the mathematics comprehension of the student.

c) There are different ways to understand a problem.

d) There are different levels of comprehension in every theme and they are never reached the first time.

The consideration of using technology within a problem solving activity must at least take into account:

a) Technology used must not be near or superior in complexity to the problem.

b) Use of technology must be significant. It must be justified that the problem can't be solved without the use of this technology or at least, it must conform as a tool that enables the student to focus on concepts and mathematical comprehension.

These elements are normally considered as a basis for the creation of a common problem. Besides, we must consider some particular elements in any problem solving activity.

Based on the accomplishment of the above considerations and the basic principles of the program, adde d to the ITESM mission's objectives, the following dimensions for the design of a PBL activity are proposed:

- **Environment:** it refers to the real situations that may occur when the activity is taking place. These situations focus on the level of comprehension achieved or used by the student just as in the traditional scheme.
- **Curriculum:** the content on which the activity is based. The curriculum is the traditional basis of teaching, but a problem solving activity underlies other elements.
- **Frame of analysis:** It refers to the curricula of the integrated areas. Previous goals and future goals are taken into account to make the problem easier and to detect future necessities.
- **Use of Technology:** The technological elements (software, laboratory, etc.) that conform the activity. This dimension must establish an analysis of its significance and the role it has in such activity.
- **Development of formative objectives:** within the ITESM context, this dimension naturally caters to those AAV's stated in its mission.

Once the problem is determined, it may be endowed of these dimensions. Their lack may sometimes result in modification or disposal of the problem. The importance of creating a consistent network of problems with the above dimensions allows student to enforce the faith of the student regarding the goal of each activity.

The projects involve several of the elements and dimensions. They belong to a different level of knowledge and occasionally they have more similarity with open-ended problems. For this reason, we want to focus on PBL and EIC activities. All of them use technology (reason for considering it as a design dimension).

In a typical session of "Principia" three stages are observed. They are summarized in Table 3. The idea of these stages is to introduce students step by step until able to manage the solution by themselves. So, in some activities steps I & II may be omitted. These steps are always omitted in any EIC activity.

The creation of a network of problems under these considerations that establish a frame of analysis, allows evaluating the recurrence to previous and future subjects. In this way, the whole network is more important than the problem itself because it allows to give continuous sense to PBL activities within the course.

The use of PBL in mathematics and physics courses has not constituted a distortion to education for students currently in the program. The evaluation of the students in this program has been inside their comprehensive evaluation (including all courses). The consistency of results in proficiency of problem solving is strongly correlated with the global results obtained for each student. Effectiveness of these kind of activities is more influenced by teacher's preparation for leading an activity than by student preparation [23].

5. Studies about the effectiveness of the program

The department of institutional effectiveness of ITESM (DEI-RZS), has been the area which has evaluated the project since its beginning, with the help of the teachers who work on it. Since 1998, more than 14 studies about the effects in the learning of students who participate in Principia have been done. Studies have been both: qualitative and quantitative. They are very local but then they are expanded to a very global one. We show only some aspects of evaluation of effectiveness scheme.

a) Collaborative activities index

Several studies on the effectiveness of the program network problems have been performed. Figure 1 shows an index of consistency of each problem in an intermediate course of "Principia"; together with the result that is obtained by dividing the student evaluation in the activity by the global evaluation in the period, the standard deviation is obtained. So an index above 1.0 means that activity is easy, an index under 1.0 means the activity is complex, for the group. These charts allow us to determine corrections on the activities and adapt them each semester. This test is administered to a group of 60 students.

b) Students opinion about the program in the development of AAV's

About the evaluation that students made of the program, the following test was administered and had following objectives:

- Analyzing the effects of "Principia" on the development of AAV's.
- Comparing the effects of "Principia" with equivalent courses.

The characteristic elements of the test were:

- Leadership
- Analysis, synthesis
- Critical thinking
- Communication
- Teamwork
- Creativity
- Search for and management of information
- Entrepreneur spirit
- Quality and excellence
- Use of technology
- Work capacity
- Self-Learning
- Problem solving
- Learning
- Motivation

The student was asked to compare the level in which the course contributed to develop each ability, attitude or value of the above statements with the average of the other courses. A scale 0-10 was used, where 0 is less, 5 equal and 10 more. In previous research [24] one of the authors reported some preliminary data on students' self-perception of skill development. Students were formally assessed on oral and written communication. The test was administered to three groups of students as described below.

"Principia" group *Students in* *"Principia" courses*	*Witness 1 group* *Students in equivalent non "Principia" courses with "Principia" teachers*	*Witness 2 group* *Students in matching courses with non "Principia" teachers*
126 students	154 students	111 students

Figure 2 shows comparative results for each group and the dimension of the research in which the smallest and the highest difference with respect to the evaluation given to "Principia" was obtained (full description of test in [22]).

c) Evaluation based upon measurable observation through evaluations

The following test (Figure 3) compares three different groups in the same course (final course of the program). One of them corresponds to "Principia" program, another (traditional) to the way it was taught in 1995 and at last, to the way it is currently being taught under circumstances of the new educational model of ITESM (reengineered). Some aspects derived from the evaluations of the proposed activities in the course are compared. They show on an indirect way the evidence of the dimension compared (the evaluations are based on a 0-100 scale).

Actually, a new test was given and results are being processed, based on the criteria that compare, with a witness group, the development of two groups ("Principia" and reengineered) the capability to solve integrated problems. This study will finished in July 2002. The research is intended to measure the recurrent effect of the execution of collaborative activities, use of technology and those of "Principia".

REFERENCES

[1] McGehee, J. *Developing interdisciplinary units: A strategy based on problem solving*, School Science and Mathematics, **101** (7), 380-389, (2001).

[2] James, R., Bailey, M. & Householder, D. *Integrating science, mathematics, and technology in middle school technology-rich environments: A study of implementation and change*, **100** (1), 27-35 (2000).

[3] Roebuck, K.I., & Warden, M.A. *Searching for the center on the mathematics-science continuum*, School Science and Mathematics, **98** (6), 328-333 (1998).

[4] Barrows, H. S. & Tamblyn, R. M. *Problem Based Learning: an Approach to Medical Education*. New York: Springer, 1980.

[5] Barrows, H. S. *A taxonomy of problem based learning methods*. Medical Education, **20**, 481-486 (1986).

[6] De Graaff, E. & Bouhuijs. A. J. *Implementation of Problem Based Learning in Higher Education*. Amsterdam: Thesis Publishers, 1993.

[7] Stevens, S. A. R. & Wilkins, L. C. *Engineers: Designers--No Alibis*. Paper presented at the National Biennial Conference of the Design in Education Council (Alice Springs, Northern Territory, Australia, July 5-7, 1993).

[8] Woods, D. R. Problem-Based Learning for Large Classes in Chemical Engineering. *New Directions for Teaching and Learning*, **68**, 91-99 (1996).

[9] Achilles, C. M., Hoover, S. P. *Exploring Problem-Based Learning (PBL) in Grades 6-12*. Paper presented at the Annual Meeting of the Mid-South Educational Research Association (Tuscaloosa, AL, November 1996).

[10] Williams, B. *Initiating Curricular Change in the Professions: A Case Study in Nursing.* Paper presented at the Annual Meeting of the American Educational Research Association (Chicago, IL, March 24-28, 1997).

[11] Glasgow, N. A. *New curriculum for the new times: a Guide to Student-Centered Problem Based Learning*. Thousand Oaks: Corwin Press, 1997.

[12] Jones, B.F. Rasmussen, M. & Moffitt, M. C. *Real-life Problem Solving*. Washington: American Psychological Association, 1997.

[13] Dods, R. F. *An Action Research Study of the Effectiveness of Problem-Based Learning in Promoting the Acquisition and Retention of Knowledge*. Journal for the Education of the Gifted, **20**, 423-437 (1997).

[14] Milbury, P. *Collaborating on Internet-Based Lessons: A Teacher and Librarian SCORE with PBL*. Technology Connection, **4**, 8-9 (1997).

[15] De Graaf, E. and Cowdroy, R. *Theory and practice of educational innovation. Introduction of Problem-Based Learning in architecture: two case studies*. http://www.ijee.dit.ie/articles/999986/article.htm. Last revision 12 february, 1997.

[16] Artigue, Douady et al., *Ingeniería didáctica en educación matemática*, Grupo editorial Iberoamérica, 1995.

[17] Polya. *How to solve it*. Dover, 1948.

[18] *Cómo plantear y resolver problemas*, Trillas, México, 1965.

[19] *Matemáticas y razonamiento plausible*, Tecnos, Madrid, 1966.

[20] *Mathematical discovery*, Vols. 1 y 2, Wiley, 1962/1965.

[21] Kouba, Vicky L., *Self-Evaluation as an act of teaching*, Mathematics teacher, **87** (1994).

[22] Pirie, S. R. B. & Kieren, T. E. *Creating constructivist environments and constructing creative mathematics*, Educational Studies in Mathematics, **23**, 505-528. Kluwer Academic Publishers, 1992.

[23] Prado, Carlos y Santiago, Rubén, *La definición de actividades y de los roles del profesor y el alumno dentro de Principia*, Reporte interno del departamento de matemáticas del ITESM-CEM, 1998.

[24] Polanco, R., Calderón, P. & Delgado, F. *Effects of a Problem-based Learning program on engineering students' academic achievement, skills development and attitudes in a Mexican university.* Paper presented at the 82^{nd}. Annual Meeting of the American Educational Research Association. Seattle, April 10-14, 2000.

Semester	*Mathematics*	*Physics*	*Computer Science*
First	Single variable differential calculus. Vector functions and differential equations.	Mechanics.	Microsoft office and Mathematica.
Second	Single and multiple integral calculus. Vectorial fields.	Mechanics, elasticity, thermodynamics.	Matlab and C++.
Third	Multiple integrals and ordinary differential equations. Probability and statistics.	Electromagnetism and modern physics.	Numerical methods.
Fourth	Differential equations systems and modeling.	Study of mechanic and electric systems.	Simulation.

Table 1. The general curricula of Principia

Technology	*Activities*	*Objectives*
Matlab and Mathematica	Projects, practice and homework assignments.	To permit student applies physics, mathematics and computer knowledge to problems of higher complexity than ones studied in traditional courses.
Use of the internet and Learning Space	Lectures and assignments.	To ease the process of collecting information. Apply the technology in the process of learning-teaching. Link the student with the technology.
Laptop	Projects, homework and practice assignments.	To link student with the cutting edge technological elements.
Microsoft Office	Projects, presentations, homework and assignments.	To develop numerical and graphical strategies for problem solving and written and oral skills.
Equipped classroom.	The entire project.	Ease some learning process (work, visualization).

Table 2. Technology, AAV and objectives.

STAGES OF A PROBLEM RESOLUTION ACTIVITY			
	STAGE I: acquisition of knowledge	**STAGE II: Collaborative Learning.**	**STAGE III: Problem**
Instructions and rules	**Teacher:** does not give the information, but gives orientation and feedback to each team. **Student:** each team may access the necessary sources of information. .	**Teacher:** keeps the information and gives feedback on the performance and amount of participation of each expert. **Student:** can't interact with other teams. Allows each expert to talk in each section of the activity.	**Teacher:** keeps the information. Watches the time and gives advice on the objective to the team. **Student:** can't interact with other teams and allows to each member participates the same.
Action elements	• They define specialty fields. • They conform expert teams based on the ability of each student.	• An application activity is defined. It must allow the interaction and interchange of experiences from each student with his/her team members.	• A problem that involves the use of previous stages is proposed. • And of other contents within the analysis frame proposed.
Way to work	Each team is divided to form expert teams integrated by elements from different teams.	The base team gets together to solve an intermediate problem where each expert contributes to the team with individual knowledge.	The base team is oriented as a team to solve the problem.
Evaluation	Each expert team makes a presentation and is evaluated according to the activities specified in the outline.	The field evaluation (in what refers to efficiency and teamwork).	The evaluation centers in the report on site that the team prepares.

Table 3. Complete stages of a Problem solving activity

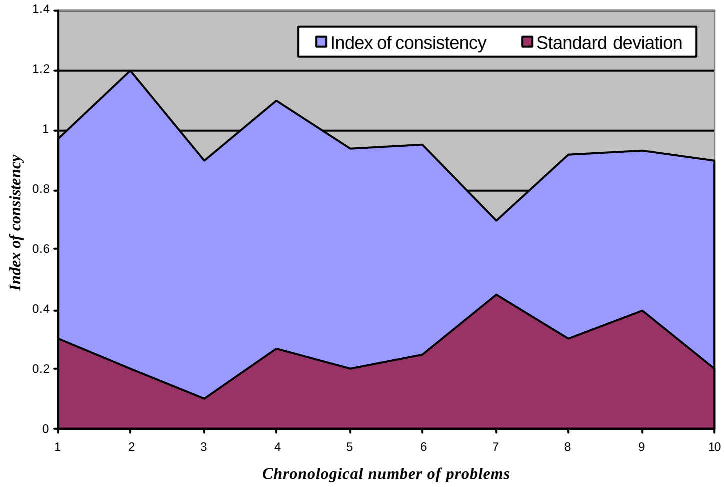


Figure 1. Index of consistency of a group of problems

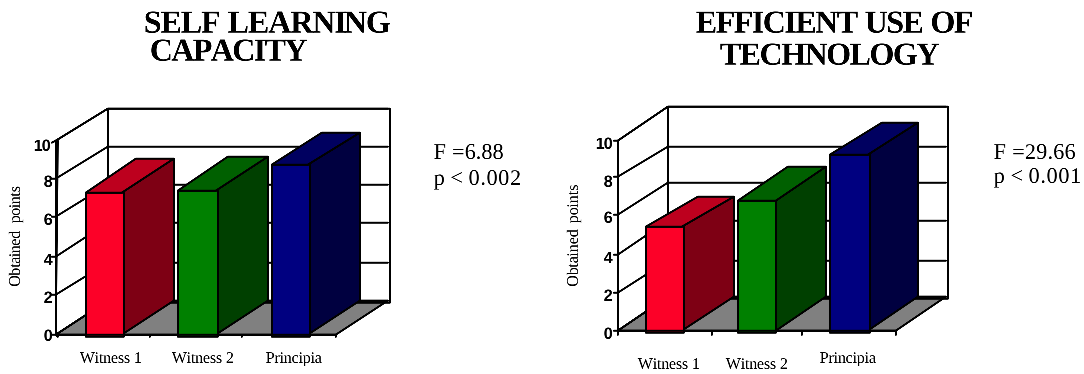
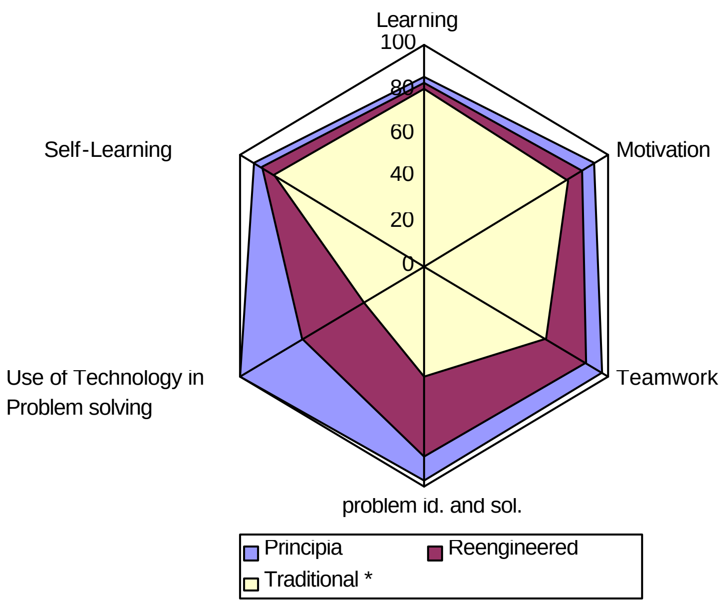


Figure 2. AAV with smallest and highest difference in evaluation with respect to "Principia" courses according to the opinion of students.



*Referring a previous research (1998)

Figure 3. Comparison of the different schemes of teaching-learning at ITESM, in relation with "Principia" program, based on student's evaluation. These students are taking one of the final courses of the program.