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A Self-Learning Environment based on the PBL Approach: An Application to the Learning Process in the Field of Robotics and Manufacturing Systems*

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This paper deals with a PBL approach used to bridge a teacher-centered learning to a student-centered learning. It has been applied in undergraduate and graduate courses of robotics and manufacturing systems with successful results. A cognitive analysis of the relationships between abilities and the steps to solve problems has been carried-out to follow the actual behavior of the students during the evolution of the course, as compared to the assumed one. Our goal was to maintain a permanent challenge among the students that allows them to discover the relevant aspects related to understanding, stating, representing and solving real world problems.

INTRODUCTION

IMPORTANT OBJECTIVES of an engineering course include the learning of concepts and the solution of problems related to the topics in the curriculum. The problems treated in the course should cover the process of understanding, statement and search of different alternatives for their solution [1]. The curriculum of an engineering course seems to be naturally designed around the solution of problems, which in the best of the cases should be real world problems, where the main goal is that the student develops enough abilities and skills. These abilities and skills are related to the analysis, abstraction, interrelationships between the main actors of the problems to be solved: inductive reasoning and analogy. They are needed to learn to state, represent and solve engineering problems, which will be part of their daily tasks in the real life.

However, traditional learning models related to engineering education in Mexico are teacher-centered. The instructor presents the concepts and issues as a lecture, without establishing important challenges to the students. In addition, most of the coursework does not take into consideration real world situations. This results in important drawbacks mainly related with the motivation of students, and a lack of interest in the course. The only interest the students exhibit is to obtain good results in exams in order to pass the course.

The problem

Given this way of teaching, an interesting, but unsatisfactory, situation appeared. The students usually tackle a problem without making an analysis to understand, state and solve it. This practice is frequently used in courses with programming activities, where the students write a program even in the absence of a previous analysis. At the end of the course, important frustrations may show up, when they feel that they do not know how to solve problems at all.

THE OBJECTIVE

Our main purpose is to build a student-centered model based on a PBL approach, which serves as a bridge from a teacher-centered environment to a self-learning environment. This model must contain a substantial cognitive component and must be further tested in undergraduate and graduate courses.

The greatest challenge in both courses is the change of learning methods, because the students have been following courses in a traditional way during their studies.

THE MODEL

The model contains, as a key ingredient, the establishment of a permanent situation of challenge among the students. The challenge is portrayed as the solution of problems, in such a way that the attitudes acquired by the students should maintain a state of permanent self-motivation during the

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evolution of the course. One of the most important moments of the learning process occurs when the students take over the course, because, from this moment on, conditions are given to establish a self-learning environment. Afterwards, the student is able to search real world problems and then to understand, set, represent, and propose alternatives for their solution. Another important characteristic of the model is that the students improve their capacities for the analysis, synthesis, abstraction, generalization, search for analogies, establishment of interrelationships between components of the system, and increase the teamwork abilities. The development of these capacities allows them, at the same time, to increase their skills to state and solve problems related to the course. A way of measuring the success of the model is when the students use meta-cognition principles to explain examples by using the cognitive abilities they acquired.

The model has the following main characteristics:

- The instructor presents concepts and sample problems, and induces the students to pose questions as an important part of the learning process.
- He then analyzes a problem at several levels of abstraction along two tracks: a bottom-up and a top-down model.
- He now poses ill-structured problems to be solved as part of the challenges [2].
- He then insists on the fact of understanding and representing a problem.
- The students are required to search for real world problems [3].
- The role of the teacher should gradually evolve from a principal actor to a guide, or mentor; otherwise a high risk of chaos can be created resulting in an uncontrollable situation. [4, 5].
- The group must search for teamwork attitudes based on problems of common interest.

Learning scenarios within the course

Since graduate and undergraduate courses are significantly dissimilar, we present them as scenarios, and proceed to compare the situations that evolved in each one.

Undergraduate course: Integrated Manufacturing Systems. Number of students: 16. Domain of studies: Engineering of Computer Systems (7 students) and Industrial Engineering (9 students).

- *General objective of the course:* To apply concepts and techniques of manufacturing systems to choice, implement, design and evaluate an integrated manufacturing system; as well as to learn how to use tools and instruments of a computer-aided flexible manufacturing system.
- *Main topics to be covered:* the Concept of Product Life Cycle; Concurrent Engineering; Robotics; Group Technology; Numerical Control Machines; Programmable Logic Controllers; Manufacturing Planning and Control; Integrated Computer-Aided Manufacturing.
- *Dynamic of the course:* Four teams were formed, each with 4 students. A restriction was placed: there should be at least one computer systems student, and no more than two, in each team. The main challenge to the students was to propose the solution of a real world problem related with the automation of manufacturing processes.

Graduate course: Multi-Robotic Cooperative Systems. Number of students: 7. Three advanced master students and 5 Ph.D. students in Computer Sciences.

General objective of the course: To apply problem statement and solving of distributed cooperative dynamic systems to a current research by the instructor: A Robot-Soccer negotiation domain. Another goal is to extrapolate the skills acquired in problem statement and solving of Robot Soccer to the distributed decision-making belonging to other domains.

Main topics to be covered: Distributed dynamic problems; problem representations at several levels of abstraction; planning models; offensive and defensive team strategies; models of distributed decision-making.

Dynamic of the course: Two teams were formed: team 1 was composed of two master students and one Ph.D. student. Team 2 was composed of three Ph.D. students and one master student. The main goal of team 1 was to develop defensive team strategies. Group 2 was involved in improving offensive team strategies reported in [6]. The main challenge to the students was to develop good algorithms so that they could participate in two parallel events to be held in Korea in May 2002: the World Championship of Soccer-Robots and the World Congress of Soccer-Robots.

Behavioral analysis

Figures 1 & 2 show curves representing the behavior of the students during the course. The vertical axis represents a sequence of steps to be executed in order to reach phase 3, where the [key] knowledge construction step is located. The Horizontal axis represents the time associated with the degrees of self-learning. The intersection of the K-CONST step with the Self-Learning Level IV is seen as a knowledge constructivist zone, widely known in cognitive science as the Zone of Proximal Development (ZOPED) [7]. The choice of four self-learning levels is merely arbitrary and corresponds to a division of the semester in four parts.

The phases are composed of a set of variables as follows. Meaning of variables:

- P-UND: Problem Understanding
- P-STAT: Problem Statement
- P-REP: Problem Representation
- PLAN-EXE: Planning and Execution
- FB-ANAL: Feed Back Analysis
- META: Meta-Cognition
- K-CONST: Knowledge Construction

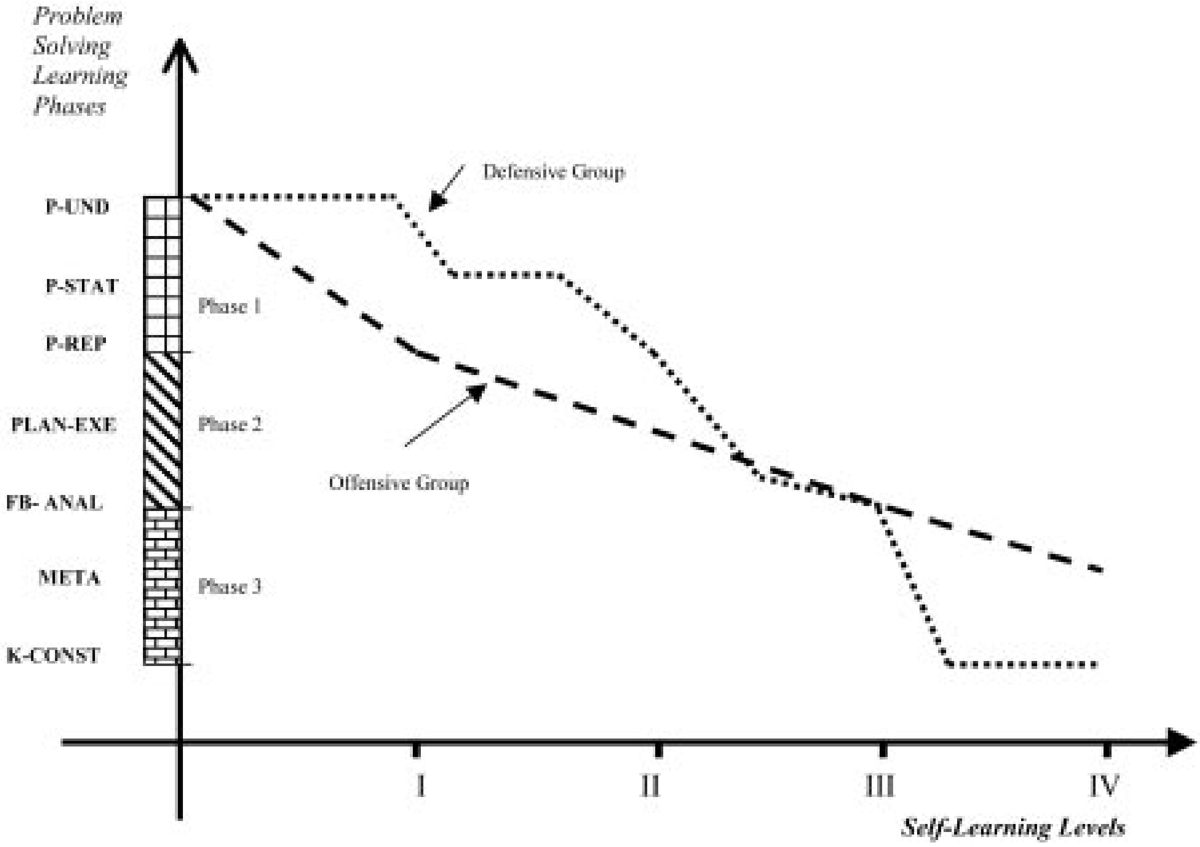

Fig. 1. Behavior of the graduate course.

The sets of variables related to the phases 1, 2 and 3 are as follows:

- Phase 1 (P-UND, P-STAT, P-REP): Analysis, Synthesis, Abstraction, Inter-Relationships & Characterization. Basic attitudes: Investigation and teamwork.
- Phase 2 (PLAN-EXE, FB-ANAL): Analysis, Synthesis, Abstraction, Generalization, Inter-Relationships, Characterization, Induction,

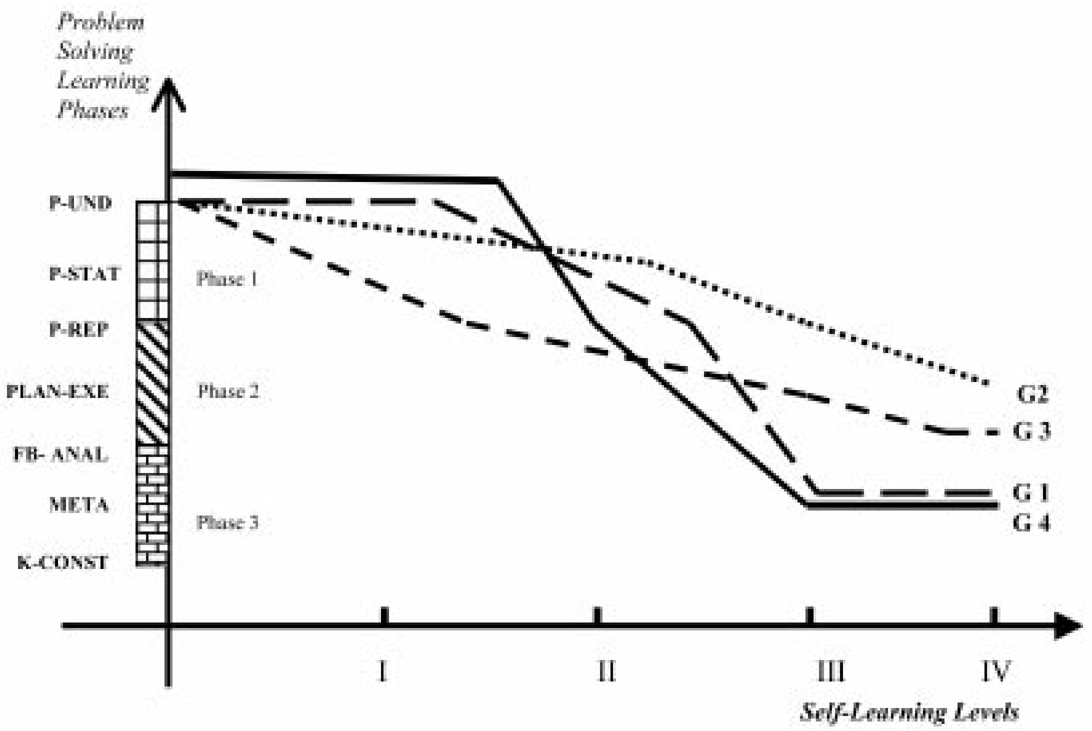

Fig. 2. Behavior of the undergraduate course.

Modeling & Analogy. Basic attitudes: Investigation and Teamwork.
- Phase 3 (META, K-CONST): Analysis, Synthesis, Abstraction, Generalization, Inter-Relationships, Characterization, Induction, Modeling, Analogy, Conceptualization & Discovery. Basic attitudes: Investigation and Teamwork.

The attitude of investigating is always present in the students of the graduate program as an essential element of the curriculum. On the contrary, the undergraduate students do not use necessary to investigate during their studies.

GRADUATE COURSE

Figure 1 shows graphs that represent the behavior of groups 1 and 2. Based on these, it is observed that the defensive group has taken more time on phase 1 than the offensive group. There was a concurrence of both groups, between periods II and III, during the phase 2 (planning and execution). However, the group capable of reaching the phase 3 during the period III was group 1. Moreover, in spite that group 1 designed defensive strategies, this group actually beat group 2 in several matches, and also reached the zone of meta-cognition and knowledge construction. This can be explained as follows: group 1 has assumed a deeper attitude of analysis. Consequently, they built richer abstractions, inter-relationships and characterizations than group 2. That is the reason of the importance of phase 1. It can be concluded that the deeper a team makes progress in this phase, the stronger their bases to build and discover knowledge are.

UNDERGRADUATE COURSE

In this course, four teams were assembled. Figure 2 shows four curves that represent the learning behavior of teams 1, 2, 3 and 4. There is a coincidence with the graduate course during the phase 1, because team 1 and team 4 have adopted an attitude of making a deeper analysis, which constituted the difference with teams 2 & 3. Due to the behavior during phase 1, teams 1 & 4 could reach phase 3. The leader of group 1 was a female student of industrial engineering, whose main attitude was to be very analytical. In team 4 there were two students, a female and a male, both of them of very analytical nature. They shared the leadership of the group. The female was a student of industrial engineering, while the male majored in computer engineering. The industrial engineering students tend to make structural analysis during their studies. In these contexts the representation of links between the components of the system is very important. On the contrary, in teams 3 and 4 the leaderships were computer engineering majors. It is well known that the students of this field are prone to code a program without dedicating important efforts to a previous analysis of the problem. We thus concluded that the attitude related to analysis gives important fruits that are reflected in phase 3, where meta-cognition and knowledge construction is situated.

The teacher should identify the leader of the group because he is the more sensible to accept the challenges. Nevertheless, this action should be discrete. Otherwise, the other members of the group can give up the interest to the course feeling that they are not involved.

One of the main characteristics of the graduate course concerns research as an important part of the curriculum design. That is the reason why the behavior represented by the curves is different and none of the groups of the undergraduate course reached the ZOPED. It is now evident that a problem-solving context is useful to convert declarative knowledge into useful skills and situated knowledge, which can be applied as successively approximate learning productions [8] that can be eventually mapped with an appropriate ontology such as time-analysis [9].

CONCLUSION

It has been proved that the teacher-centered learning model does not allow the students to develop cognitive abilities necessary to solve problems. On the contrary, the student-centered learning model is an alternative solution to this problem, which is enriched by integrating the PBL approach as mechanism to maintain the student in a permanent challenge and consequently in a constant motivation.

In this work, an analysis of the relationships between cognitive abilities and the steps to solve problems in order to monitor the behavior assumed of the students during the evolution of the course has been carried out. It has been shown that an attitude to make a deep analysis of a problem provides tools to understand and build richer abstractions, interrelationships and characterizations to represent a problem, make plans, build, and discover knowledge.

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