Project oriented learning for basic robotics using virtual laboratories and intelligent tutors

L. Enrique Sucar[1], Julieta Noguez[2], Gilberto Huesca[3]

Abstract - We have developed a course for teaching basic robotics, at the undergraduate level, with several new didactical and technical contributions, aimed at helping the students learn in a more effective way. The guiding thread for the course is based on the Project Oriented Learning didactic strategy which promotes interdisciplinary integration, capacity of analysis and synthesis, true teamwork, leadership, and knowledge sharing. The course integrates three developments. Firstly, we have developed a virtual laboratory based on a 3-D simulation, which lets students explore the first concepts in the course: mechanical design, sensors, and control, before they start building a physical robot. Secondly, an intelligent tutoring system guides the students during their interactions with the virtual lab. Finally, the students form teams to build a small mobile robot for a competition. We present the results from several years of teaching this course, as well as an evaluation of how the virtual laboratory and the tutor can help accelerate and improve the learning process.

Index Terms – intelligent tutoring system, project oriented learning, virtual laboratory, robotics.

INTRODUCTION

An ever increasing number of academic institutions are undergoing a search for new methodologies and didactic techniques, which enable undergraduate students to face real professional situations [7]. This is particularly important for interdisciplinary fields, such as robotics, which require the integration of knowledge of different areas, and several skills for effective learning. In particular, we are combining project oriented learning, virtual laboratories and intelligent tutors in an innovative course in which the students learn the basics of mobile robots by building and programming a robot for a competition.

The Project Oriented Learning (POL) didactic strategy portrays active learning as an educational paradigm that transforms direct experience into a tool for supporting, and stimulating learning [1]. We are using POL as the main didactic strategy for an undergraduate course in mobile robotics at ITESM Campus Cuernavaca. The course is for Computer Science and Electrical Engineering majors at the sophomore level. Based on POL and collaborative learning, the students learn by doing. They form interdisciplinary teams that must learn about mechanical design, kinematics, sensors, control, and artificial intelligence in order to design a robot for a competition requiring actions such as line following, maze solving, rescuing, etc. To support this process, we have developed several tools, especially an intelligent tutoring system coupled to a virtual laboratory, which facilitate and guide the learning process, particularly in the first stages of the course [8].

We have developed a virtual laboratory based on simulation. Using a 3-D simulator, the students can explore the first concepts in the course: mechanical design, as well as sensors and control, before they start building the physical robot. An intelligent tutoring system guides the students during their interactions with the virtual lab, providing the student with the opportunity to learn through exploration and giving him/her personalized help.

The key element of this environment is a representation of the student model based on probabilistic relational models. This student model has several advantages: flexibility, user adaptability, high modularity and facility of model construction for different scenarios. The model keeps track of the students' knowledge at different levels of granularity, combining the performance and exploration behavior in several experiments, in order to decide the best way to guide the student in the subsequent experiments, and to re-categorize the students based on the results.

We present an evaluation of the virtual lab and of the tutor, and of the course, in general. Based on a questionnaire, most of the students consider that the virtual laboratory is useful for learning the relevant concepts, and 80% enjoyed the learning environment. In this test group, some students used the virtual laboratory with the tutor and others only the virtual lab. The experiments show that the students with the help of the tutor have a better performance than the others. For evaluating the course in general, we show the results from the

[1] L. Enrique Sucar, Professor, Dept. of Computer Science, Tecnológico de Monterrey , Campus Cuernavaca, esucar@itesm.mx
[2] Julieta Noguez, Assistant Professor of Computer Science, Tecnológico de Monterrey, Campus Ciudad de México, jnoguez@ritesm.mx
[3] Gilberto Huesca, M.Sc. Student, Computer Science, Tecnológico de Monterrey , Campus Cuernavaca,, A00952592@itesm.mx

students' opinions, based on questionnaires, and the results of their participation in several national competitions.

PROJECT ORIENTED LEARNING

POL is one of several active learning methods, devised during last decade as a product of research on collaborative learning in the fields of the behavioral and cognitive sciences. POL considers that student teams will work on a single guiding thread, or project, for an entire course [3].

Students must organize themselves into teams, and play roles while delegating work amongst themselves, and while delivering feedback to their teams [9]. Overall success in these terms is not easily measurable. Since most of the learning process will take place outside the realm of the computer system, learning has to be assumed whenever there is evidence of its existence through visible actions [4]. Besides, it is hard to prove that students are motivated to learn when the instructor applies POL to their classroom activities. Johnson states "… changing to a cooperative style is not simple. There is a big difference between putting students into groups to learn… and structuring your teaching so students learn cooperatively..." [5].

The project oriented technique provides the following advantages [9]:

- It allows the students to learn how to solve problems using relevant knowledge independently of the discipline source.
- Activities are focused on exploring and working out a practical problem with an unknown solution.
- Activities are designed in such a way that they can involve several areas of the same discipline or the interaction of different disciplines.
- Project oriented courses consider in their design the application of interdisciplinary knowledge so the students can appreciate the relationship between different disciplines in the development of a particular project.
- The project assignment promotes the search of open solutions so students are free to create new knowledge.

We designed the pedagogical aspects of course based on this collaborative didactic technique.

COURSE DESCRIPTION

We will describe some of the main characteristics of the mobile robotics course.

I. General objectives.

The students must learn the basic concepts of mobile robotics, first by experimenting in a virtual laboratory, and later by building a small mobile robot for a competition. Throughout the course, the students design, build and program a small mobile robot to participate in a competition, requiring activities such as line following, maze solving, rescue, etc.; learning on the way the basic concepts in several fields relate to mobile robots, mechanical and electronic design, sensors, control, programming and artificial intelligence. They have to assimilate, integrate and apply all these concepts in multidisciplinary teams. The desired abilities to develop in the course are: team work, honesty, leadership, self directed learning, creativity, and the capacity to identify and solve problems.

II. Course contents.

This basic robotic course covers the following topic: mechanics and electronics concepts, sensors and actuators, robot vision, robot architectures, programming, control, map building, planning, Markov decision process, reinforcement learning and human-robot interaction.

III. Learning Activities.

In the first part of the course, the basic concepts of mobile robotics are covered in weekly lectures. During this period, the students use the virtual laboratory to practice these basic concepts in mechanics, kinematics, sensors, programming and control. During the 5th week, students form teams, and select the competition in which they will participate. They start building and programming their robot taking advantage of the experience in the virtual lab. Concurrently, advanced topics in planning, learning and reasoning are covered in the classroom. In the last stage, the students incorporate these techniques in their robot, according to the competition goals.

The reflection process is a very important tool for students. They need to construct a portfolio for learning-by-doing management, conflict resolution, and overall synthesis of all products, derived from the team activities and their integration in a robot prototype. It also serves to point out elements that have not been completed; and, thus, contributes overcoming flaws which may appear throughout the course.

IV: Course Project.

The main focus of the course project is to design and build a robot to participate in a competition. For example, the 4th Latin American IEEE Student has both beginner and advanced categories. An example is the Lego beginner category: a game is defined to develop solutions for autonomous mobile robotic problems. Two teams need to design, build and program two robots with different abilities which are placed in an arena (a *robotics manipulation pharmacy*), in order to produce a *drug* according to a prescription without any human interaction. Robots read the prescription after the beginning of the challenge.

V. Assessment process.

For the course assessment, three milestones of the project are considered with respect to the robot development phases of the competition chosen. The total evaluation of the course is formed of different aspects, which are shown in Table 1.

TABLE I
COURSE ASSESSMENT

Points	
25	Learning activities (virtual laboratory practices, homework, group process, etc)
30	Advancement of project (3 milestones)
20	Midterm and final exams
25	Final robot competitions

The last course had 20 subjects enrolled, with five teams of 4 students each. The students chose on their own the desired competitions. In this case, the competitions selected were maze solving and Lego beginners.

USING POL TO EVIDENCE LEARNING

During this course, a guiding thread that asks the students to build a small mobile robot, and a technical documentation of project, are continuing. The project has the following phases:

- The students constitute teams; they make contractual agreements, and choose the competition.
- Each team designs (mechanics, electronics and sensors) and builds their robot (1st milestone).
- Students specify the software architecture and develop the basic software modules –control (2nd milestone).
- Teams develop the high-level programming modules, integrating all in a functional robot (3rd milestone).
- Teams participate in the competition.

The group process to develop the project consists of establishing the following steps:

1. At the beginning of the course, we ask the students to reflect on their expectations of the course, their actual knowledge level concerning the course, and their commitment to contributing to the success of the course.
2. Each team is formed according to each member's strengths and weaknesses.
3. Commitment contract. From the fifth week on teams will be formed, and will start their team project. At this point, they make and sign a formal contract specifying the roles of each participant. Each team includes four members, and during each phase of the semester the leading role is changed
4. The teams are asked to present weekly reports on the advances of the robotic project, in which they make individual and collaborative reflections.
5. The students must satisfy the requirements of three milestones, and a final presentation, including technical reports which explain the progress of the project.

By reading the reflections and assessing skills and learning goals, the instructor uses this information to supervise the progress of each team. We combine team reflections of self-perception with teacher assessments based on the technical goals delivered.

SEMI-OPEN LEARNING ENVIRONMENT

We have developed a virtual laboratory based on simulation. Using a 3-D simulator, the students can explore the first concepts of the course: mechanical design, sensors and control, before they start building the physical robot. As the laboratory assistant, we have incorporated an intelligent tutoring system that guides the students during their interactions with the virtual lab, providing the student with the opportunity to learn through exploration and giving him personalized help. The tutor is based on a probabilistic-relational student model, assessing the effectiveness of the learner exploration behavior. Based on this model, the tutor can decide the best way to guide the student in the next experiments, and can re-categorize the student, based on the results of each experiment.

We developed a semi-open learning environment which provides the student with the opportunity to learn through free exploration, but with specific performance criteria that guide the learning process. In the robotics virtual laboratory, we considered important aspects of open learning environments, because the student has the liberty to explore different parameters to observe their effects inside the virtual lab: however each experiment has specific objectives that the student needs to achieve. This enables an effective assessment of the exploration behavior.

We defined a sequence of specific experiments to enable the assessment of the knowledge items, step by step. The first experiment involves robotics' mechanical design concepts as shown in figure 1.
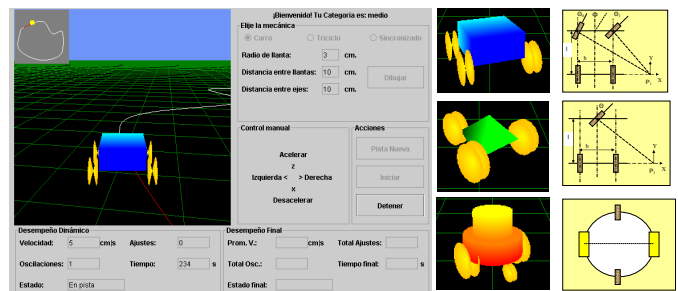

FIGURE 1
EXPERIMENT ON THE MECHANICAL ASPECTS OF MOBILE ROBOTS: KINEMATIC CONFIGURATION.

The educational goals are: (i) to learn mechanical aspects of mobile robotics, and (ii) to practice with different kinematics models using manual control. The second and third experiments are designed to explore basic properties of infrared (IR) sensors (which are used in the basic competitions). The fourth experiment is related to actuators and control theory. The results of each experiment, in terms of exploration and performance, are considered in the student model.

In the design of the virtual lab, we have considered a balance between the simulation capabilities versus the tutoring decisions such as when to interrupt the experiment, the student performance follow up, task planning, etc. [8].

SYSTEM ARCHITECTURE AND PROBABILISTIC RELATIONAL STUDENT MODEL.

The basic architecture of the robotics virtual laboratory is depicted in figure 2. In order to provide students with suitable instruction, the knowledge base contains a representation of the experiments and related concepts, such as mechanical and IR sensors, as well as a representation of the parameters for exploration, like rotation angles, distances, sensor calibration, etc.
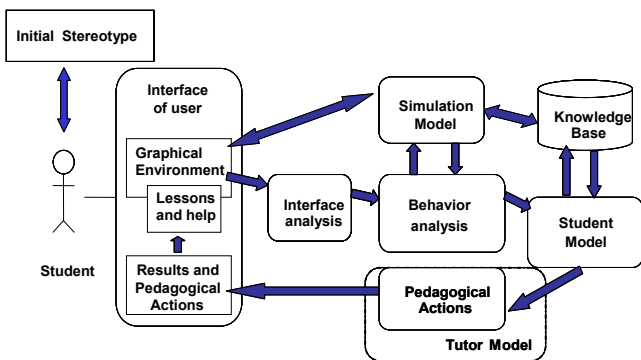

FIGURE 2
BASIC ARCHITECTURE OF THE ROBOTICS VIRTUAL LABORATORY

Every simulation environment uses variables that express its state, including the results of the students' trials. There is a predefined goal, and the student has several opportunities to achieve it. The knowledge base is used extensively by the student model to produce its assessment.

We designed a *Probabilistic Relational Models* (PRM) to characterize the student model, allowing the domain to be represented in terms of entities, their properties, and the relations between them.

A PRM [6] combines an object oriented representation, in terms of classes, objects and attributes, with Bayesian networks (BN). Using Bayesian networks, we represent the dependencies between attributes within a class, and also between different classes. Using this model, we have a general representation of students, knowledge items, and experiments (as a data base), which can be adjusted to a particular student and to experiments into a Bayesian network. Using standard probabilistic inference techniques, the BN is used to propagate the observations of the student's performance in order to update the model at different levels of granularity.

The student model is represented as a PRM which has a hierarchical structure, as shown in figure 3. We partitioned the experiment class, according to our object of interest, creating two subclasses: experiment performance and experiment

behavior, which constitute the lowest level in the hierarchy. The intermediate level represents the different knowledge items (concepts) associated with each experiment. These items are linked to the highest level, which groups the items in sub-themes and themes, and finally, into the students' general category.

When a student performs an experiment in the virtual lab, an inference mechanism is used to propagate evidence from the experiments' evaluation to the knowledge items, and then, to the knowledge sub-themes and to the knowledge themes. Based on this evidence and the accumulated evidence from previous experiments, the system decides whether to re-categorize the student.

After each experiment, the knowledge level at the different level of granularity, items, sub-themes and themes, is used by the tutor to decide if it should provide help to the student, and at what level of granularity. For this, we currently use a rule-based system (in the future it will be implemented as an influence diagram).
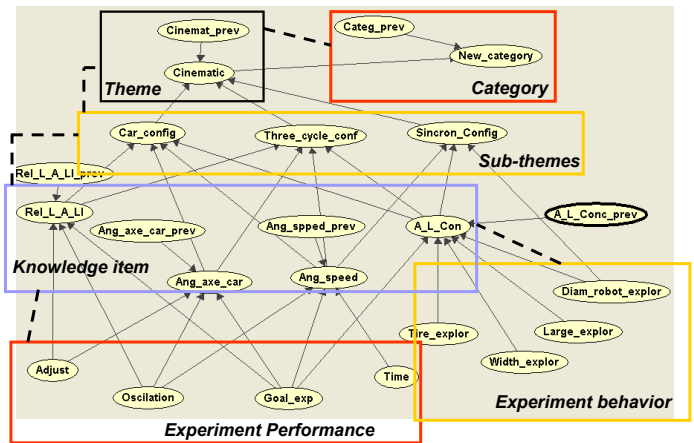

FIGURE 3
RELATIONAL STUDENT MODEL. STRUCTURE EDGES CORRESPOND TO CONDITIONAL PROBABILISTIC DEPENDENCY BETWEEN ATTRIBUTES OF THE SAME AND DIFFERENT CLASSES.

The initial knowledge level for each sub-theme and theme, and the initial category of the student, are automatically determined from the student's record using a Bayesian network. These are updated each time the student performs an experiment, so the model has also a dynamic structure. The student model changes at the different levels of granularity, as the learner explores the relevant exploration parameters, and as they reach goals related with the experiment performance.

The PRM student model is integrated within a data base, and an authoring tool, that facilitate the construction of the model for different experiments and domains. The instructor can specify the relevant exploration and performance parameters for each knowledge item, and then, the relations between items, sub-themes and themes.

EVALUATION PROCESS

We present, firstly, an evaluation of the virtual lab and of the tutor, and, secondly, of the course in general.

I. Virtual laboratory evaluation.

We have concluded a user study with the semi–open learning environment. In particular, we evaluated the tutor and the student model, using the virtual robotics laboratory. By analyzing the learners' explorations, as they used the system, we have some insight on the general effectiveness of experiment performance. We obtained quantitative and qualitative results that give some measure of the prediction capabilities of the proposed student model, and of the utility of the tutor in a semi–open learning environment.

- **Participants.** The subjects were EE and CS undergraduate students at the sophomore and senior levels. A total of 20 subjects, enrolled in a robotics basic course participated in the study. Although there were few students, we decided to divide them into a control and an experimental group to test the VL issues with ITS and without ITS.

- **Experiment design.** In the experiment, all subjects used the virtual laboratory, described in the semi-open learning environment section. We introduced the academic background of each student to the system. The system, using the probabilistic model, applied the pre-categorization process for each student. Both, control and experimental group students were divided in two categories: novice and intermediate. We, then, applied the pre-test after a 60 minutes lecture on basic robotics concepts. The pre-test is paper and pencil test designed to evaluate the learners' knowledge of the objects target by the virtual laboratory. It consisted of 25 questions organized in the same way as the knowledge objects of the student model. Both, control and experimental groups participated in a session (30 to 60 minutes), performing experiments with the virtual laboratory. The experimental group had the support of the tutor during the experiments, while the control group explored the virtual lab without tutor.

- **The post-phase.** The post-test consisted of a test analogous to the pre-test, with 25 questions organized in a same way as the knowledge objects of the student model, and of a ten item questionnaire targeted at students' opinions about their virtual laboratory experience. In addition, the system produced log files that capture the sessions at the level of basic exploration actions and experiment performance results.

II. Results

Figures 4 and 5 show the initial categorization results versus the pre-test for the first knowledge objects targeted by experiments 1 and 2 (the graphs show the averages of the 20

students). The knowledge values for the pre-categorization model were defined based only on academic background. For the students categorized at the intermediate level (figure 5), the predictions of the model are very good for almost all the knowledge items. For the novice student, we found that, in general, the predictions are below the test results. However, a lecture was given just before the pre-test was applied, so we think that this affected the results in particular for the novices.
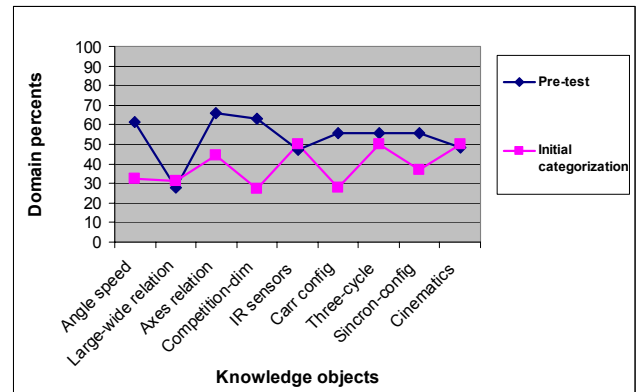

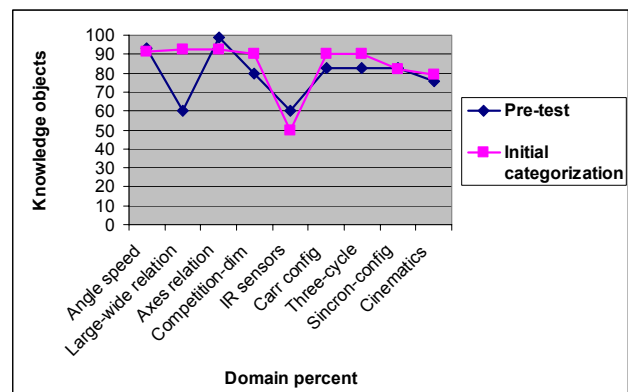FIGURE 4
INITIAL CATEGORIZATION VS PRE-TEST FOR NOVICES

FIGURE 5
STUDENT CATEGORIZATION VS PRE-TEST FOR INTERMEDIATE

Figures 6 and 7 summarize the results after experiments 1, 2, 3 and 4, for the control and experimental groups. The graphs of *tutor* and *without tutor* represent the knowledge objects (items, sub-themes and themes) assessed inside of the virtual laboratory for the control and experimental groups. The graphs of *pre-test* represent the knowledge objects assessed by a paper and pencil test, before students complete the experiments using the virtual laboratory. The results for novice students (according to the initial categorization) are shown in figure 6, and those for intermediate students are shown in figure 7. The results show that the students that explore the virtual environment with the help of the tutor have the better performance. As shown in these figures, students with intelligent support improved their knowledge level of the targeted knowledge objects significantly.
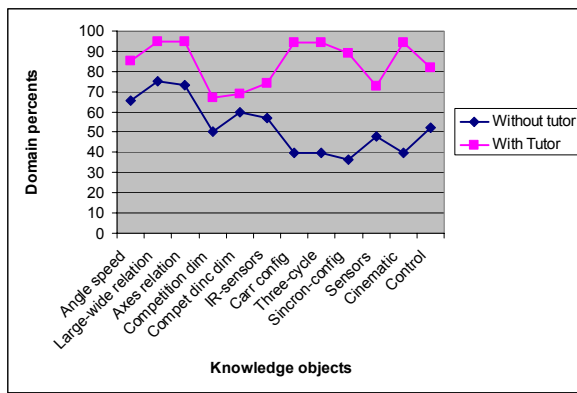
FIGURE 6
RESULTS FOR NOVICE STUDENTS AFTER PERFORMING
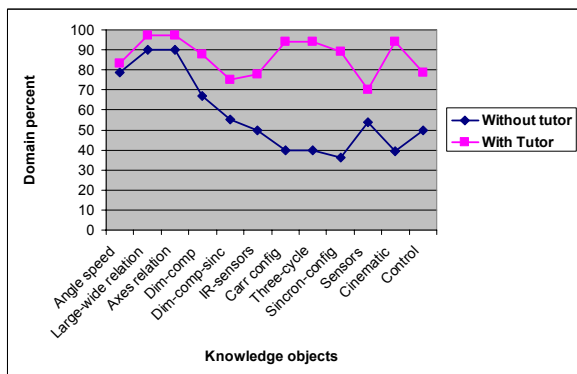EXPERIMENTS 1, 2, 3, AND 4.

FIGURE 7
RESULTS FOR INTERMEDIATE STUDENTS AFTER PERFORMING
EXPERIMENTS 1, 2, 3, AND 4.

Additionally, based on a questionnaire, most of the students consider that the virtual laboratory is useful in learning the relevant concepts, and 80% enjoyed the learning environment.

III. Course evaluation

For evaluating the course in general, we obtained the results from students' opinions, based on institutional questionnaires. These questionnaires have 28 specific questions related to teacher skills, skills developed, teacher-student relationship, and academic quality. The assessment range is from 1 to 7, where 1 is excellent and 7 is worst. The average assessment in the last term was 1.33.

The results of the team participation in several national competitions during the last three years were good, in general. For instance, they obtained second and third places in line maze competitions in 2003 and 2004, and a second place in obstacle avoidance in 2002. These are good results, considering that our students were competing with experienced participants and graduate students, while our students were enrolled in their first robotic course; and additionally they were competing for the first time.

CONCLUSION AND FUTURE WORK

We have developed a course for teaching basic robotics at the undergraduate level with several didactical and technical contributions, helping the students lo learn in a more effective way. The first part of the course uses an intelligent tutoring system coupled to a virtual laboratory for mobile robots, which constitute a semi–open learning environment. The virtual laboratory can be visited at:

http://doc.mor.itesm.mx:8181/robotica

Send an e-mail to the authors for an account.

The ITS keeps track of the students' knowledge at different levels of granularity, combining the performance and exploration behavior in several experiments, in order to decide the best way to guide and to re-categorize the student. We have evaluated the system with an initial group of students. The results show that the students who explore the virtual environment with the help of the tutor have a better performance, and students with intelligent support improved significantly their knowledge level of the targeted knowledge objects. In the future we plan to incorporate additional web-based simulation tools as a didactical aid for agent programming. We also plan to apply the evaluation of the VL and the tutor, with more students to improve the statistical validity of our results.

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