Wireless4x4: an integrating learning experience for Telecommunications students

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Abstract—**The Telecommunications Engineering degree contains the study and understanding of a wide variety of knowledge areas, like signal theory and communications, computer networks or radio propagation. This diversity of fields makes it hard for the students to integrate all these knowledge, which in turns results essential to tackle real and practical problems that involve different subjects. As a response to this need of integration, in University Rey Juan Carlos an educational project based on Problem Based Learning (PBL), called the Wireles4x4 Project, has been carried out. In this project, groups of students build a complete system that is able to autonomously drive a radio controlled car, involving different technologies such as wireless communications, positioning systems, power management or system integration. The objectives of this educational project are: (1) The development of an active learning methodology, by which the students acquire integrated knowledge and skills on a variety of subjects; (2) The acquisition of professional skills like teamwork capabilities, oral and written communication, and long term task scheduling; (3) The participation of the students in an interdisciplinary engineering project with time and budgetary constraints. The results show that the participating students improve not only their specific knowledge on the involved issues, but also their capability of integrating different subjects of the degree and the skills for autonomous learning.)**

Keywords: integrating learning; problem based learning; professional capabilites training; telecommunication engineering.

I. Introduction

The Wireless4x4 project is an annual educative project developed by students and educators at Universidad Rey Juan Carlos, in Fuenlabrada, Spain. Specifically, the participants of this learning experience are members of the Telecommunication Faculty (ETSIT, from its Spanish name *Escuela Técnica Superior de Ingeniería de Telecomunicación*), in which three five years degrees and one six years degree are offered, all of them closely related with information technologies.

Each of these degrees contains the study of a wide variety of knowledge areas and professional skills, like signal theory, communications theory and practice, electromagnetic fields and radio propagation, computer networks, data processing, programming fundamentals or electronic design. Along its five or six years, the students follow a plethora of different courses which sometimes are not conceptually connected. Therefore, it is often hard for the students to integrate all this knowledge and skills, which is itself an essential capability that a telecommunication engineer is expected to apply in his professional career. Moreover, the professional market requires engineers that not only manage different technical knowledge and skills, but also are used to face with real problems with real constraints and are able to work in teams, organize a long-term work and make public presentation of their results with clarity and determination. All of these professional skills are hardly acquired with the classical learning methodology.

Therefore, the Wireless4x4 is an innovative learning experience, based on Problem Based Learning (PBL) techniques [1], [2], which represents an effort of Universidad Rey Juan Carlos to overcome these limitations of the conventional educative procedures. Then, the main objectives of the project are:

- The development of an active learning methodology, by which the students acquire integrated knowledge and skills on a variety of subjects.
- The acquisition of professional skills like teamwork capabilities, oral and written communication, and long term task scheduling.
- The students' involvement in an interdisciplinary engineering project with real time and budgetary constraints.

The project is organized as an extra course, recognized as a sixty hours course. Moreover, the students' designs are tested in a final public competition, which is a race in a pre-set circuit in the ESTIT campus. The best design is awarded with a prize for all the members of the winner group, like PDAs or laptops. The participants of this project are students of each of the degrees of the ETSIT, who are in their third or higher year. This constraint is necessary to count on the participation of students with a minimal base of knowledge on communication systems, electronics and programming. Before the final exams in June, the following year project is presented in the classrooms and with posters, in order to motivate the participation of the students.

The students participate in groups of three members, which during these years has shown to be an appropriate number to develop all the tasks, while avoiding the problem of having parasite students in the project. Because of resources constraints, the project can hold three groups (this year has grown up to four) per year, so among the candidate groups (this

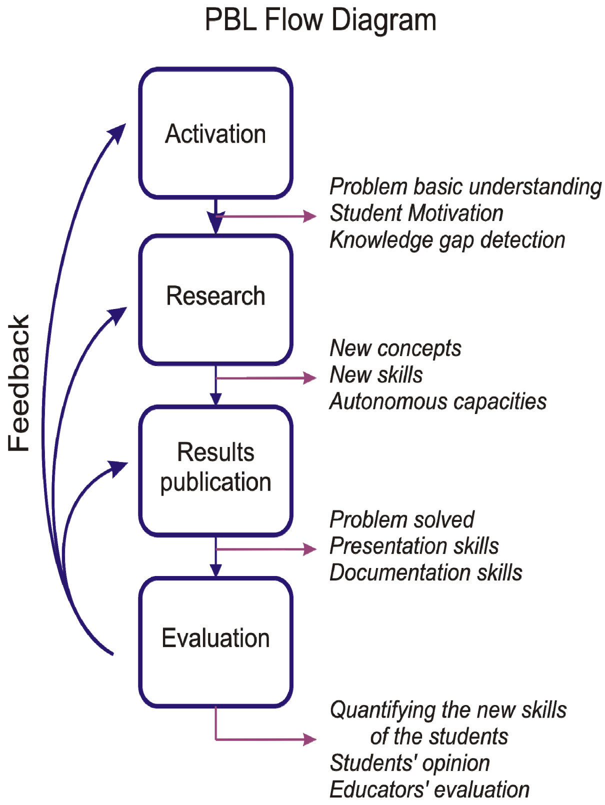

Figure 1. A typical PBL diagram with four phases and the expected results for each phase.

year there were six) a selection procedure is carried out, which is in turn a first step in the motivation-activation phase of the PBL project.

From a technical perspective, in this project the groups of students build a complete system that is able to autonomously drive a radio-controlled car. The control of the vehicle trajectory is carried out by an autonomous algorithm, that is executed by a control computer away from the vehicle, using the GPS (*Global Positioning System*) coordinates obtained by an on board computer.

The on board computer is also capable of controlling the servomotors which controls the speed and direction of the vehicle. A WiFi network performs the communication between control and on board computers. The power of the on board system is provided by a common battery, so a power management system is also implemented. Then, different knowledge and skills related to signal processing, positioning algorithms, wireless communications, electronic, programming and system integration are needed to complete the Wireless4x4 project.

The remain of the paper is organized as follows. In Section II, a brief introduction to PBL methodology and phases is provided. Then, the learning methodology and the project description are described in depth in Section III. The results of the three-fold evaluation procedure are given in Section IV, and in Section V the main conclusions of this experience are drawn.

II. PROBLEM BASED LEARNING

According to H. S. Barrows [3], the father of the PBL methodology, problem based learning is "a learning method based on the principle of using problems as a starting point for the acquisition and integration of new knowledge". In general, the student's learning process is stimulated with a problem, and for solving the problem, the student discover what to learn and how to do it. The main function of the problem is, then, to motivate the learning process. At the end of this process, the students not only has acquired a set of skills and competences, but also has learned how to autonomously acquire new ones [4], [5].

On the one hand, the main advantages of this active methodology is that the students learn very important professional skills, like how to search information, solve problems, work in teams and build new knowledge. Moreover, the students are demanded to deeply investigate the subject of the problem, not only to learn basic theoretical concepts. On the other hand, the main drawback of this learning approach is that it requires more time to cover the same amount of knowledge than a classical approach. Moreover, the cost of this kind of learning experiences is higher, and the number of students in each group needs to be reduced. However, with more reduced and realistic syllabus, and the help of information technologies these drawbacks tend to be minimized.

Figure 1 represents a general flow diagram of the four main stages of a problem based learning procedure [6]. Firstly, a motivation phase is needed for activating the previous knowledge about the subject, define the new knowledge that the students will need to acquire, preparing a scheme to deal with the problem, and properly motivating the students. Secondly, in the research phase the students autonomously search, filter and interpret the information needed for solving the problem. Then, in the third phase, the solution is documented and published.

Finally, the very important evaluation phase is critical for the improvement of the educative project. This evaluation phase should contain objective criteria and subjective opinions from both the students group and the participating educators. Since this project is repeated each year, the feedback from this stage to the previous ones is needed to modify the planning for the future.

III. METHODOLOGY

In this section we describe the Wireless4x4 project using a two-fold approach. Firstly, we emphasize the learning methodology as a particular case of the general four-stage scheme presented in Section II. Secondly, a description of the project is presented to clarify one of the main aspects of this experience, which consists of the integration of knowledge from different subjects of the telecommunication degree.

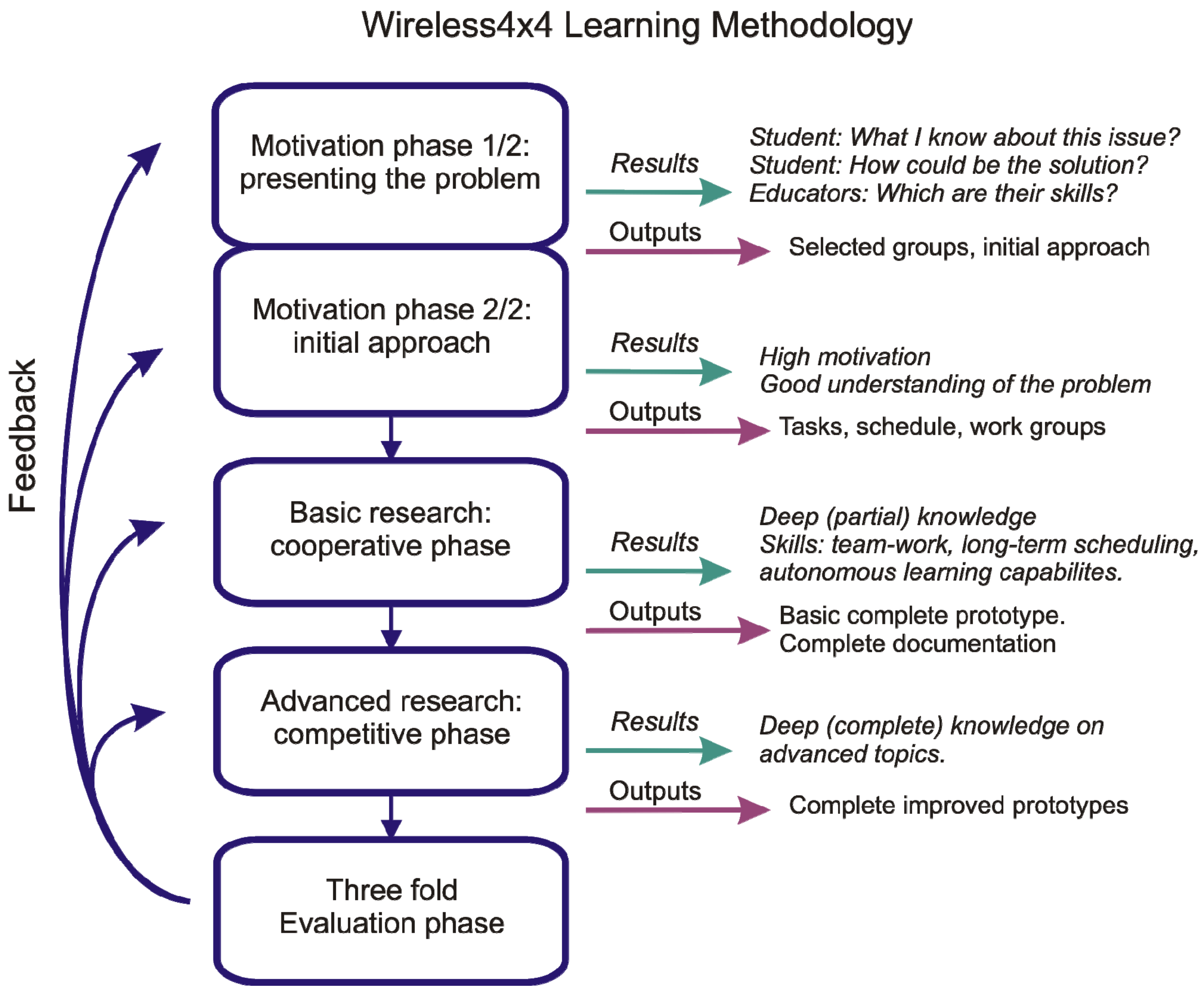

Figure 2. Wireless4x4 learninng methology: flow diagram with the expected results and the objective outputs of each phase.

A. Learning Methodology

Figure 2 represents the learning methodology of the Wireless4x4 project. Four phases are used (the first one being divided in other two). The expected results of each phase and the objective outputs (products, documentation, indicators) are also shown.

1) Motivation phase.

The main two ideas of this project are that the students develop an autonomous learning effort for solving a real life problem and that they acquire a integrating perspective of different technologies involved in that problem. For this purpose, it is essential that the students are motivated enough to face inherent difficulties of those both ideas. To accomplish this, in the motivation phase the students participate in a group interview in which only the best and most motivated groups are selected for the experience. In the selection procedure, both the students' records and the motivation of the group are taken into account. Furthermore, in this first interview, a global perspective of the problem is provided, and the students are requested to design a solution during fifteen minutes with the help of a computer connected to the Internet. This way, three objectives are attained. Firstly, the students discover what they know about the problem and the main gaps they have to cover for fulfilling the task. Secondly, they begin to feel curiosity about what could be the best solution. Thirdly, the educators gets a global perspective about the qualification of each group, which, in turn, on the one hand helps in the selection procedure and on the other hand underline which knowledge and skills should be learned by the students in the following phase. This is also the first evaluation point of the project. The result of this first part of the motivation phase is therefor a selected set of participating groups and a base of motivation for all the participants.

In the second part of the motivation phase, the problem is described in detail, and a first approach of the solution is investigated. For this purpose, a group session involving all the selected participants and the educators is carried out. In this session, the educators present the problem and the time, resources and cost constraints. Also, a previous simplified version of the project is shown to the students. Then, using a brainstorming approach, the general solution is investigated by the students. The output of this phase is a design of the different parts that are involved in the project, and an assignment of the tasks of each part to a different group. Also in this session, the initial groups are interleaved, according to the preferences of the students and the difficulty of each task. The result of this phase is that each student is highly motivated to try to complete his task, since they have selected it and they know that the whole project depends on each single participant.

2) Basic research and resolution phase

After the motivation phase, the interleaved groups start the second block of the project, which is the basic research and resolution phase. In the session described above, each of these groups was assigned a particular task. Moreover, all the students and the educators know the main gaps that the groups have in their knowledge and skills. Therefore, in this phase each group carries out a deep research in its own part of the project, propose a solution for the specific sub-problem, design it with the appropriate tools, implement the solution, test it, and prepare a detailed documentation. The main task of the educators in this phase is to lead each group with suggestions about how to find the solution, provide the students with the necessary tools, and supervise that each task can be completed on time. Finally, all the groups incorporate their respective parts of the solution to a common platform, thus building a first basic solution for the whole system. Moreover, in an intermediate group session, each group presents its solution to the rest of the groups. This is the intermediate evaluation point of the project. The result of this phase is that each member of each of the initial groups has acquired a deep knowledge of a part of the project, but adding all the expertise of each of its components, each group has a full vision of the final solution.

3) Advanced research and resolution phase

This intermediate group session is also the starting point for third block of the project, the advanced research and resolution phase. Here, the initial groups are restored and their main objective is to improve the basic solution implemented in the cooperative previous phase in order to improve their final prototype. For this purpose, each group will propose an improvement to the educators, who will lead them to find the information needed for its development. In this phase each group gets an advanced expertise about one or more particular issues related, for example, to control theory, location algorithms, electronics or signal processing. The output of this block is a finished prototype for each group. The result is that, within each group the knowledge of the previous phase has been shared, and knew knowledge and skills have been acquired by all of its members.

Finally, a competition among all the groups is organized. The main objectives of this phase are to evaluate each one of the final solutions found by each group and to develop an interesting marketing task for the next year project among possible new participants. This is the final evaluation point of the project. Moreover, this competition and the prizes are part of the initial motivation for the students.

4) Evaluation

The project has a three-fold evaluation. Firstly, an evaluation of the technical knowledge and professional skills acquired by the students is made using the results of the three evaluation points (initial, intermediate and final) described above. Secondly, a survey of the students' opinion was carried out, investigating the main aspects of the project, that is: its interdisciplinary content, the practical approach used, and the general methodology (see Section IV for details). Thirdly, a final evaluation was made among the participating educators, related to the educational aspects of the project and the workload.

B. Project Description

The Wireless4x4 project follows a practical and integrated approach of several knowledge areas that are tackled in different subjects of the ETSIT degrees. The project is based on PBL methodology and hence the students are responsible to acquire the knowledge and skills needed for the achievement of the objectives and requirements described at the beginning of the project. Moreover, the students must face the technological, time and budgetary constraints that are typical in engineering projects.

The final aim of the Wireless4x4 project is the design, implementation, test and demonstration of a complete communication system that is able to autonomously drive a radio controlled car. The control of the vehicle trajectory must be carried out by an autonomous algorithm, which is executed by a control computer away from the vehicle, using the GPS coordinates obtained by an on board computer. A WiFi (IEEE 802.11b) network performs the communication between the control and on board computers. Hence, the knowledge areas involved in the project are:

- Analog circuit design and implementation: for the on board power supply system.
- Digital communications: for the implementation of the WiFi network.
- Embedded software and hardware systems integration and configuration: for the design and implementation of the hardware and software platform.
- Signal processing and control theory: for the implementation of the autonomous driving algorithm based on the GPS information.
- Software development: for the implementation of JAVA programs running in both control and on board computers.

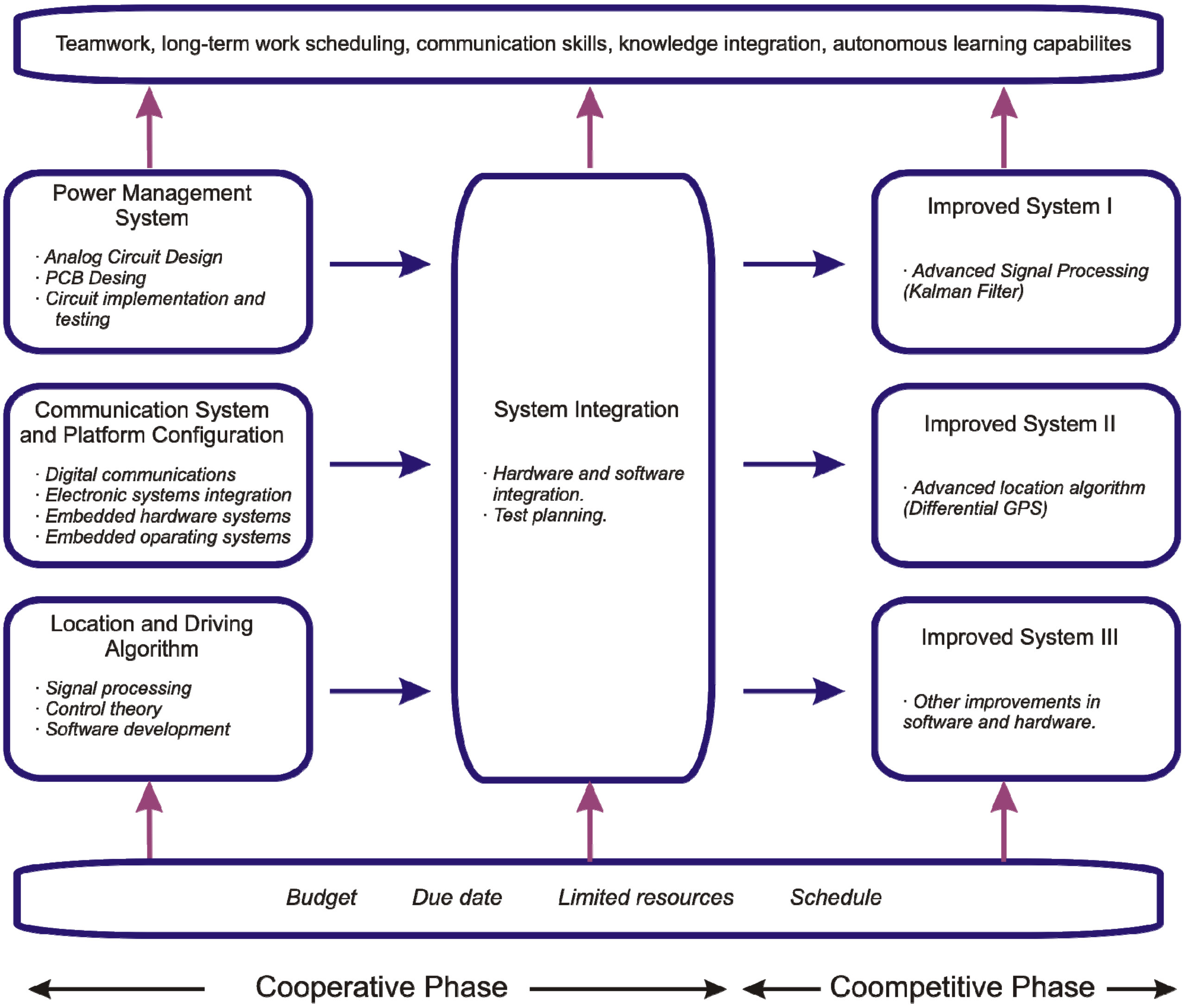

Figure 3. Wireless4x4 learninng methology: flow diagram with the expected results and the objective outputs of each phase.

- System integration: for the integration of hardware and subsystems to complete the whole system.

The students should be able to relate the concepts from these knowledge areas and to adapt them for solving the real problem considered in this project. At the end of the project, each group of students will have to build a fully functional prototype, within the proposed deadline, and to participate in the race against the rest of groups. Therefore, the student faces a realistic environment with task deadlines, budgetary constraints and limited resources, all of them shown in Figure 3 as lower inputs of the process. Moreover, as shown in that figure, the Wireless4x4 project is divided in two phases, cooperative phase and competitive phase, corresponding with basic research and advanced research phases, respectively. Now we describe the particular tasks that the groups must carry out in these two phases.

1) Cooperative Phase

As explained above, there are several areas of knowledge involved in the project. Thus, the students have to face up a hard initial learning curve in the first months of the project development. Hence, in this initial phase, the three groups cooperate in order to reach a common target: the construction of a basic prototype of the radio controlled vehicle with autonomous driving. Three working groups are created to develop tasks in three well separate areas. Each working group is composed by three students coming from the three original groups, so, after this initial phase, in each group there will be an expert student in each one of the three areas, and this expert student will transmit his knowledge to his teammates during the next phase. These first three tasks are:

- Task 1: Design and construction of the power management system with the requirements of the on board computer. There are several elements connected to this computer like an USB GPS receiver, an USB

Figure 4. Finished prototype with the electronic circuits on a transparent box on its top.

Figure 5. Participating students in Wireless4x4 2009 project

WiFi transceiver and a servo controller (also connected to the servos that handle the vehicle direction and speed). From a battery of 11.1V, the power supply circuit must provide the levels of voltage and current required by all the on board systems. This task also includes the physical construction of the power supply circuit on a Printed Circuit Board (PDB). The specific skills acquired with this task are: analog circuit design, computer-assisted design (OrCAD) of electronic circuits, and PCB construction.

- Task 2: Implementation of a WiFi network for the communication between the control and on board computer, and implementation of the hardware and software platforms. During this task, the students must select a suitable USB WiFi device, analyze the WiFi coverage in the campus and program the required software for the WiFi link establishment between the two computers. Moreover, the students install and configure an embedded computer with a Linux operating system, and mount the basic platform composed by the on board systems. The specific skills acquired with this task are: link budget analysis, WiFi coverage analysis and WiFi network deployment, embedded computers and embedded operating systems configuration.

- Task 3: Implementation of a driving algorithm based on GPS information. The students participating in this task must select a suitable USB GPS receiver, analyze the received GPS information and program the driving algorithm for the autonomous driving of the vehicle along a previously fixed circuit. The specific skills acquired with this task are: GPS signal analysis and processing, basic control theory and software development.

After these three tasks, all the students have to put their knowledge and designs together, in order to carry out the next task.

- Task 4: System integration to complete the autonomous driving of the vehicle. In this task the students put all the pieces together and solves the integration problems that usually arise. The specific acquired skills with this task are: systems integration capabilities.

With the conclusion of this task, the students have reached the project basic goal and the competition between groups begins.

2) *Competitive Phase*

For this last phase, the students return to their original groups to develop specific system improvements. The aim of this phase is to make the project more attractive to the students, improving their inventiveness and own initiative. Hence, this phase has only one task for the three groups:

- Task 5: Development and implementation of system improvements. The students suggest the system improvements (in the driving algorithm, signal processing or location method) and, after the educators' authorization, implement them in order to win the final race against the others groups. Examples of improvements carried out this year are: improvement of the GPS positioning using a tracking technique by means of a Kalman Filter or improvement of the positioning using a differential GPS.

During all these five tasks, the students also acquire several professional capabilities and skills, represented in Figure 3 as upper outputs of the diagram. Specifically, the main ones are related to: teamwork, long-term scheduling, communication skills, knowledge integration and autonomous learning.

IV. RESULTS

In this section, the results of the three-fold evaluation described in Section III are analyzed.

A. *Technical knowledge and professional skills*

We now analyze the objective results that have been reached in the project. For the end of the project, the three groups built their fully functional prototypes and competed in the successful race. The winner group implemented a differential GPS system and improved the speed control. However, before the race some last time adjustments were needed in all the vehicles because the designs were not robust enough. Indeed, one of the prototypes did not finish the race because of a bug in the autonomous driving algorithm. After this bug was fixed, the vehicle was eventually able to complete the circuit successfully. A picture of a finished prototype is shown in Figure 4.

Moreover, through the three evaluation points described in Section III, the educators observed the improvements in different knowledge areas and skills like programming, electronic circuit design, embedded system configuration or wireless networks in all the students. Hence, all the students had a positive evaluation due to their participation, initiative and the quality of the prototypes.

B. Students' opinion

A survey of the students' opinion was carried out at the end of the project. The survey was composed by nine closed questions about the knowledge and skills acquired by each student, and two open questions to evaluate the best and worst issues of the project. Table I shows the mean and mode values of the survey answers. Several aspects of these results are noteworthy. All the results show a high satisfaction level about the learning aspects and the general evaluation of the project. Interestingly, all the students confirm that their knowledge and skills related to the different areas of the project have been improved, even in the areas that were not related with their specific task in the cooperative phase.

However, if we break down the results of items two, three and four in Table I, it shows that, for each student, a slightly better result is obtained for the areas involved in his particular task. Although the general evaluation item mean value is very high, it is important to point out that the item related to the acquired autonomous learning capabilities has one of the lowest values.

In the open questions, the students emphasized as the best points the teamwork, the work in a real scenario and the variety of concepts learned. The worst point is the lack of resources and a sometimes-poor organization. Examples of the most outstanding answers of our students are: ``I loved the experience, beyond my wildest expectations, I would recommend it to anyone and my only regret is I cannot do it again."; ``If it hadn't been for my mates, I'm sure I'd have crashed into more things".

C. Educators' opinion

All the educators agree on that the educational value of the project is very high, in terms of both technical knowledge and professional skills. Moreover, the educators also agree with the students in most of the observations given in the previous section, in particular in the organization shortcomings. The main reason for this is the high workload that this project has represented for the involved educators. However, they still are really pleased with the final results of the project.

TABLE I. RESULTS OF THE STUDENTS' OPINION TEST

Item	*Mean*	*Mode*
Through this project my teamwork capability has improved	4.08	4
Through this project my knowledge in analog electronics has improved	3.83	5
Through this project my knowledge in software development has improved	3.42	4
Through this project my knowledge in system integration has improved	4.17	5
Through this project my problem solution autonomy has improved	3.92	4
Through this project my problem solution capacity with time and budgetary constraints has improved	4.08	5
The project is a good integration of knowledge from several areas in Telecommunication Engineering	3.92	5
The project has fulfilled my expectations	3.75	4
Project general evaluation	4.58	5

V. CONCLUSIONS

The Wireles4x4 project is three years old, and at this moment is in the cooperative phase of its fourth year. The results described in Section IV show that the main objectives of the Wireless4x4 project have been fulfilled. Specifically, the knowledge and skills acquired by the students and tested in the three points evaluation are really significant and useful.

Moreover, from the three points evaluation and the student survey, it can be seen that the students acquire an integrated vision of the different technologies involved in the project. In this sense, the main limitation is the difficulty that a student has to acquire those skills that are not related with his specific task in the cooperative phase, as can be observed in the student survey. To overcome this limitation, two improvements are being developed this year: the documentation and the final presentations of the cooperative phase are being improved, and the competitive phase is longer in order to give more time to the students to analyze the whole system.

Moreover, the organization issues of the project have been improved over these three years, but they still are one the weakest aspects of the project, due to the high workload that the project represents for the educators. This year, more professors participated in the organization of the project, and from the beginning, a list of task and a Gantt diagram has been developed and is known by all the participants.

Finally, the summarized opinion of the educators involved in the project is quite encouraging, and the authors are able to predict that this project has still a wide margin for future improvements.

A. Figures and Tables

1) Positioning Figures and Tables: Place figures and tables at the top and bottom of columns. Avoid placing them in the middle of columns. Large figures and tables may span across both columns. Figure captions should be below the figures; table heads should appear above the tables. Insert figures and tables after they are cited in the text. Use the abbreviation "Fig. 1", even at the beginning of a sentence.

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