A Multidisciplinary Problem Based Learning Experience for Telecommunications Students

Carlos Figuera, Rey Juan Carlos University, Spain

Eduardo Morgado, Rey Juan Carlos University, Spain

David Gutiérrez-Pérez, Rey Juan Carlos University, Spain

Felipe Alonso-Atienza, Rey Juan Carlos University, Spain

Eduardo del Arco-Fernández-Cano, Rey Juan Carlos University, Spain

Antonio Caamaño, Rey Juan Carlos University, Spain

Javier Ramos-López, Rey Juan Carlos University, Spain

Julio Ramiro, Rey Juan Carlos University, Spain

Jesús Requena-Carrión, Rey Juan Carlos University, Spain

ABSTRACT

The Telecommunications Engineering degree contains the study and understanding of a wide range of knowledge areas, like signal theory and communications, computer networks, and radio propagation. This diversity makes it hard for students to integrate different concepts, which is essential to tackle real and practical problems that involve different subjects. As a response to this need of integration, a group of professors at Rey Juan Carlos University carried out an educational project based on Problem Based Learning (PBL), called the Wireles4x4 Project. In this project, groups of students build a complete system to autonomously drive a radio controlled car, involving different technologies such as wireless communications, positioning systems, power management, and system integration. 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: *Concept Integration, Multidisciplinary Learning, Problem Based Learning, Professional Capabilities Training, Telecommunication Engineering*

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INTRODUCTION

The Wireless4x4 project is an annual educative project developed by students and educators at Rey Juan Carlos University, 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. Since 2009, four new four-years degrees adapted to the European Higher Education Area (EHEA) are progressively substituting the rest of the degrees.

Each of these degrees contains the study of a wide variety of knowledge areas, like signal theory, communications theory and practice, electromagnetic fields and radio propagation, computer networks, data processing, programming fundamentals or electronic design. With the classical teaching methodologies, and due to the difficulty of the engineering topics, very often the students become bored and get discouraged about their learning process (Felder & Silverman, 1988). In fact, the adaptation of the degrees to the EHEA implies not only a change in the structure and number of the courses, but also a change in the learning methodology used in each course (Cuinas & de-Lorenzo, 2010).

Throughout the five years of the degree, 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 are an essential capability that a telecommunication engineer is expected to apply in his professional career (Colomo-Palacios, 2010). Several novel methodologies have been proposed in order to improve the learning capabilities of the students in a particular area of knowledge. For example, in software engineering, different techniques such as dropped analogies and self role plays have been applied to make the concepts easier to understand by the students (Matsuo & Fujimoto, 2010; Carbonell et al., 1983; Casado-Lumbreras et al., 2009). Also, Hrad and Zeman (2010) make a general description of the situation and provide some examples of interesting learning activities in the area of electrical communications.

However, only a few numbers of works face the complex task of providing an integrating multidisciplinary education methodology in electrical engineering. In Campo et al. (2006) the authors describe a multidisplinary activity which involves technical skills learning (electronic instrumentation) together with business administration capabilities (market surveys, enterprise creation…). In Klobas et al. (2004) a learning object is proposed to facilitate the dialog between abstract knowledge and application in specific context, both in business and engineering areas. Some works (Martínez et al., 2010; Maskell & Grabau, 1998) also propose to use of Problem Based Learning (PBL) techniques as a practical tool for multidisciplinary learning projects.

Moreover, the professional market requires engineers that not only manage different technical knowledge and skills, but are also 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 (Woods et al., 2000).

Therefore, the Wireless4x4 project is an innovative learning experience, based on Problem Based Learning (PBL) techniques (Albanese & Mitchell, 1993), which represents an effort of Rey Juan Carlos University to overcome these limitations of the classical 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 ETSIT 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 any 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 have 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 year there were six) a selection procedure is carried out, which is also 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 control the speed and direction of the vehicle. A Wi-Fi 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 remainder of the paper is organized as follows. First, a brief introduction to the PBL methodology and its phases is provided. Then, the learning methodology and the project description are presented in depth. The results of the three-fold evaluation procedure are given and the main conclusions of this experience are drawn.

PROBLEM BASED LEARNING

According to Barrows (1998), 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 estimulated with a problem, and for solving the problem, the students discover what to learn and how to do it. Hence, the main function of the problem is motivating the learning process. At the end of this process, the students not only have acquired a set of skills and competences, but also have learned how to autonomously acquire new ones (Barrows, 2009; Schmidt, 1983). Several problem based learning projects have been proposed in different areas related to electrical engineering. In Mills and Treagust (2003) a review of PBL projects used in electrical engineering degrees is carried out. The main conclusion of this work is that PBL (and also project-based learning) is a suitable technique in engineering, but is usually mixed with classical methodologies during the first courses.

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 new 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. Additionally, since PBL techniques usually imply the resolution of real life-like problems, it is an unbeatable framework for integrating different parts of the curriculum of a particular degree.

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 (Mills & Treagust, 2003). 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 (Prieto et al., 2006).

Figure 1 represents a general flow diagram of the four main stages of a problem based learning procedure (Prieto et al., 2006). Firstly, a motivation phase is needed for activating the previous knowledge about the subject, defining the new knowledge that the students will need to acquire, preparing a scheme to deal with the problem, and properly motivating the students. Once this phase is finished, the students are interested in the problem, and also they are able to start a research on the topic. Secondly, in the research phase the students autonomously search, filter and interpret the information needed for solving the problem. Essentially, this is the phase where the students acquire the main knowledge and skills, since in this phase the proposed problem is solved. Then, in the third phase, the solution is documented and published. This one is also a very important phase, since the capacity of communicating their ideas within a technological framework is a very important professional skill for engineers.

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. An example of a complete evaluation procedure can be found in (de-Camargo-Ribeiro, 2008).

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. Secondly, a description of the project is presented to clarify one of the main aspects of this experience, which consists on the integration of knowledge from different subjects of the telecommunication degree.

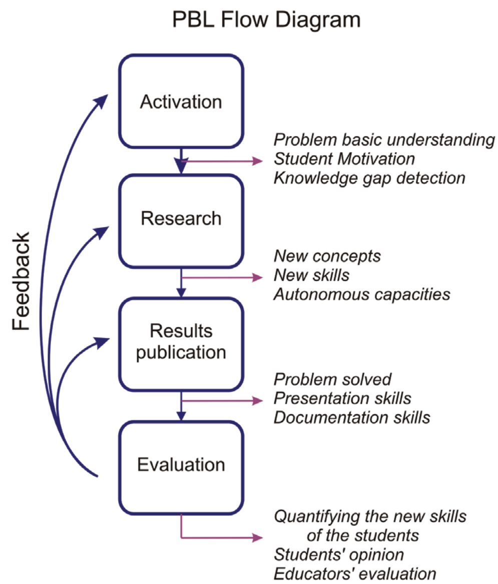
Learning Methodology

Figure 2 represents the learning methodology of the Wireless4x4 project. Four phases are used: motivation phase (which is divided in other two: the presentation and the initial approach to the problem), basic research (cooperative) phase, advanced research phase (competitive) and evaluation phase. 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 an 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 with the educators. In this selection procedure, both the students' records and the motivation of the group are taken into account to ensure that only the best and most motivated groups are selected for the experience. 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

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



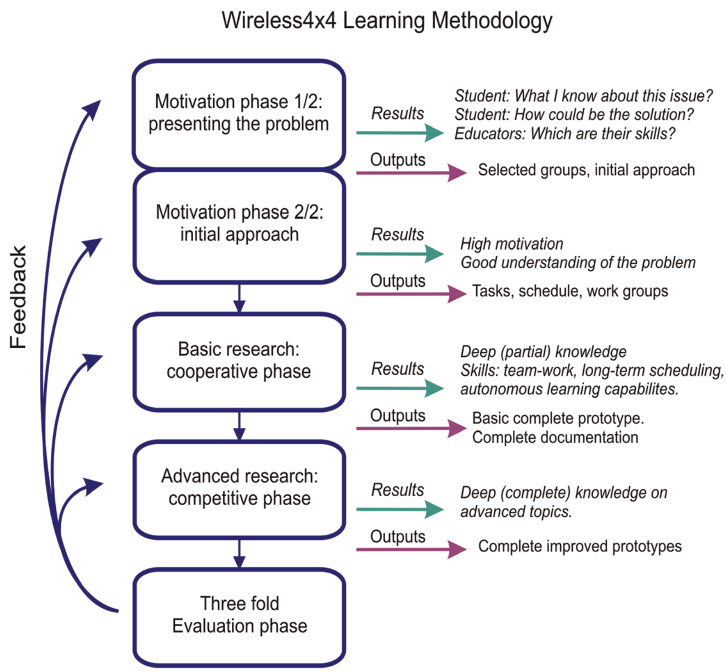
way, three objectives are attained. Firstly, the students discover what they know about the problem and the main gaps they should cover for fulfilling the task. Secondly, they begin to feel curiosity about what could be the best solution to the problem. Thirdly, the educators get a global perspective about the qualification of each group, which on the one hand helps in the selection procedure and on the other hand underlines which knowledge and skills should be learned by the students in the following phase. This is also the first evaluation point of the project in which the educators verify the knowledge of the students at the beginning of the project. The result of this first part of the motivation phase is therefore 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, an assignment of the tasks of each part to a different group of students and the schedule to carry out these tasks. This information is gathered in a Gantt chart of the whole project. To carry out these tasks, in this session, the initial groups of students are interleaved, according to their preferences and the difficulty of each task. The result of this phase is that each student is highly motivated to try to complete his task on time, since they have selected it and they know that later tasks depend on their work, so 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

Figure 2. Wireless4x4 learning methodology: flow diagram with the expected results and the outputs of each phase



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. Then, the students present and explain the executed tasks and the acquired knowledge to the rests of the students. This group session is also the intermediate evaluation point of the project in which the educators verify the knowledge that has been acquired by the students during the cooperative phase of the project. The result of this phase is that each member of each of the initial groups has acquired a deep knowledge only about a part of the project, but adding all the expertise of each of its components, each group has a full vision and knowledge of the final solution.

3. Advanced Research and Resolution Phase

This intermediate group session is also the starting point for the 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 new 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 in which the educators verify the knowledge and skills of the students at the end 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. Thirdly, a final evaluation was made among the participating educators, related to the educational aspects of the project and the workload.

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 Wi-Fi (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 Wi-Fi 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.
- System integration: for the integration of hardware subsystems to complete the whole system.

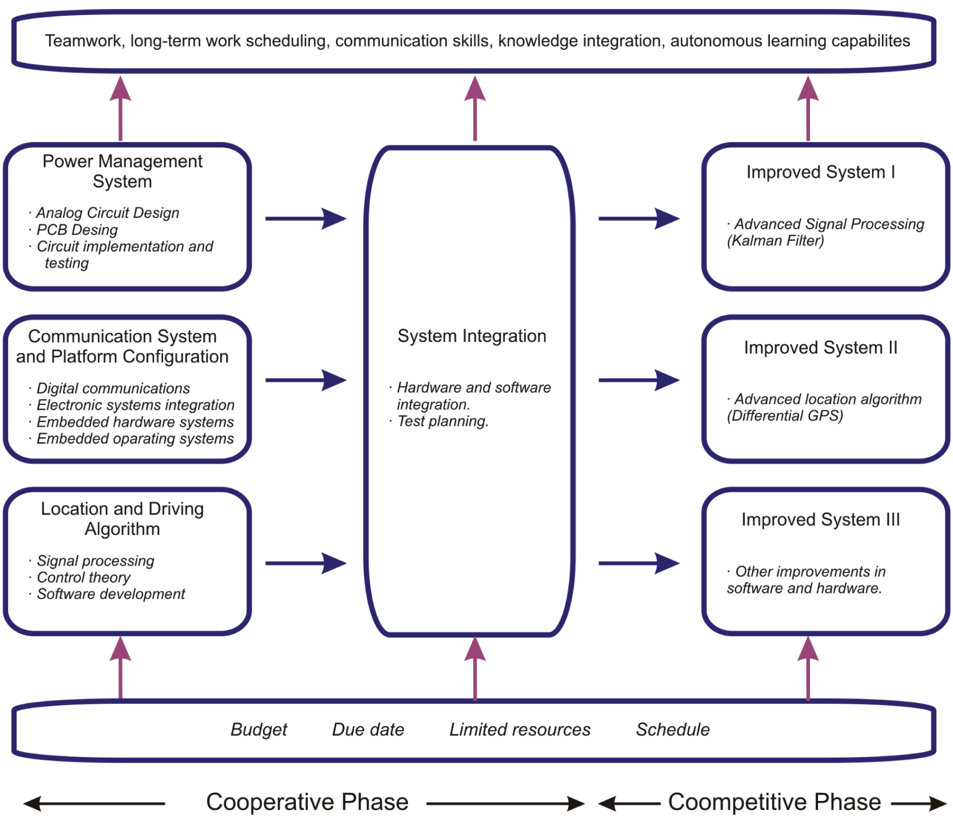
The students should be able to relate the concepts from these knowledge areas and to adapt them for solving the real problem considered in this project. At the end of the project, each group of students will have to build a fully functional prototype, within the proposed deadline, and to participate in the race against the rest of the groups. Therefore, the students face 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 into 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 Wi-Fi transceiver and a servo controller (also connected to the servos that handle the vehicle direction and speed). From a Lithium Polymer (LiPo) 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 includes not only the component selection and circuit design, but also the physical construction of the power supply circuit on a Printed Circuit Board (PDB). Moreover, the students must characterize the discharge curve of the battery to keep the system in working order and to ensure the safe use of the LiPo battery. 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 Wi-Fi 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 Wi-Fi device, analyze the Wi-Fi coverage in the campus and program the required software for the Wi-Fi 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, Wi-Fi coverage analysis and Wi-Fi 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 students must analyze the accuracy of location provided by the GPS system and, then, develop a control algorithm for the autonomous driving. This simple driving algorithm only calculates the velocity and direction of the vehicle as a function of the coordinates of the position at that moment, the position at the previous moment and the next point that traces the circuit. Moreover, the students must program the software application to introduce the coordinates of the points that trace the circuit and to track the vehicle movement.

Figure 3. Wireless4x4 project description. Lower inputs represent the constraints of the project, upper outputs represent the outcomes for the students, and middle boxes represent the project tasks



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 solve 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 among 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: the improvement of the GPS positioning using a tracking technique by means of a Kalman Filter, and the 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.

RESULTS

In this section the results of the learning outcomes obtained from the three-fold evaluation method (technical knowledge and professional skills, survey of students' opinion and educators' evaluation) are analyzed.

1. Technical Knowledge and Professional Skills

These outcomes have been evaluated according to the information extracted at the three evaluation points (initial, intermediate and final). The educators have verified students improvements in different knowledge areas and skills such as programming, electronic circuit design, embedded system configuration and wireless networks. An objective measure of the acquired knowledge and skills is that students have been able to build their own fully functional prototype. According to this, and considering students participation, initiative and the quality of the prototypes, all students were awarded with a positive evaluation.

Regarding the competition, all prototypes successfully completed the predetermined circuit. The winner group implemented a differential GPS system and improved the speed control. Even if all participants were able to compete, some last time adjustments were needed before the race in order to adjust prototypes design parameters, thus emphasizing the limited robustness of the built solution. Indeed, one of the prototypes did not finish the race because of a bug in the autonomous driving algorithm. After having this bug fixed, the vehicle was eventually able to complete the circuit. A picture of a built prototype is shown in Figure 4.

2. Students' Opinion

A survey of the students' opinion was carried out at the end of the project. This survey was composed by nine closed questions about the acquired knowledge and skills, and two open questions to evaluate the best and worst issues of the project. Table 1 shows the mean and mode values of the survey answers. Several aspects of these results are noteworthy. All the students showed a high satisfaction level about their learning achievements, even if different groups implemented different solutions and improvements to the same problem.

Interestingly, all the students confirmed that their knowledge and skills related to all areas of the project were improved, including those that were not related with their specific task in the cooperative phase. However, a deeper analysis of items two, three and four in Table 1 show that each student has given slightly better marks in those areas related to his particular task.

Also, the global project was highly evaluated by students. In spite of this high score (see mean value), it is important to point out that the item related to the acquired autonomous learning capabilities received one of the lowest marks.

In the open questions, the students highlighted the teamwork, the work in a real scenario and the variety of learned concepts. The worst issue was the lack of resources and a sometimes-poor organization. Examples of the most outstanding answers of our students

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

were: ``I loved the experience, beyond my wildest expectations, I would recommend it to anyone and my only regret is that I cannot do it again.''; ``If it had not been for my mates, I am sure I would have crashed into more things''.

3. Educators' Opinion

Educators were interviewed in order to collect their opinion about the educational outcomes of the project. The following considerations were extracted from these interviews: 1) the educational value of the project is very high both in terms of technical knowledge and professional skill, given the students learned concepts; 2) this project represents a high (while pleased) workload for the involved educators and this produces organizations shortcomings, as it was pointed out by students; 3) the difficulty of the whole project is high, and it requires a constant effort from students to overtake their knowledge limitations; 4) students acquire better knowledge in those areas where they are specialized, showing that sharing the knowledge with other peers is a difficult task; 5) additional efforts need to be done by students in order to win the race, a functional prototype is not good enough in this context. 6) those student that worked harder in the cooperative phase do not necessarily are better positioned in the competitive phase to win the race. Thus, during competition brilliant ideas make the difference.

CONCLUSION

The Wireles4x4 project is three years old, and at this moment is in the cooperative phase of its fourth year. The results described 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 evaluation points are really significant and useful.Moreover, from the three evaluation points and the students' 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 difficult for each student to acquire those skills that are not related with his specific task in the cooperative phase, as can be observed in the 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.

The organizational aspects of the project have been improved over these three years, but they still are one of the weakest aspects of the project, due to the high workload that they represent 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 have been developed and

Table 1. Mean and mode values of students survey answers, with 0 being the minimum and 5 the maximum

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

are 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. There is still potential to reach higher performance on two fundamental points: Transfer of knowledge and motivation of students. In future editions of the project, we plan to include special milestone in the collaborative phase: Each working group will give a brief presentation to the other participants about their work. This will enhance knowledge transfer before the start of the integration task, the most critical and complex one of this phase. Additionally, this milestone will increase the presentation skills of the students and their leadership.Regarding the motivation of the student, we have observed that the competitive phase challenge could be improved. For this purpose, an interesting possibility is to expand the project to other universities and hold a final race where the best team of each university faces each other in a competition based on fully autonomous driving. This competition would maintain the teaching philosophy of the original project, and it is a way of sharing knowledge about a technology that will be very hot in the coming years.

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Carlos Figuera received the Telecommunication Engineering Degree in 2002 from Polytechnic University of Madrid, Spain. He received the PhD degree on 2009. He is currently working as an assistant professor in the Department of Signal Theory and Communications at Rey Juan Carlos University in Madrid, Spain. His research interests include signal processing for wireless communications and statistical learning theory with applications to location systems.

Eduardo Morgado received a degree in telecommunication engineering from the University Carlos III de Madrid, Spain, in 2004 and the PhD degree from the University Rey Juan Carlos, Spain, in 2009. Currently, he is an associate professor in the Department of Signal Theory and Communications, University Rey Juan Carlos, Madrid, Spain. His research interests include signal processing for wireless communications with applications to ad hoc and sensor networks.

David Gutiérrez-Pérez studied Telecommunication Engineering at Carlos III University in Madrid. He is Visitant Professor at Rey Juan Carlos University in Madrid. His research area is Vehicular Communications.

Felipe Alonso-Atienza received both the M.Sc. degree in Telecommunication Engineering and the Ph.D. degree from the Universidad Carlos III de Madrid, Spain, in 2003 and 2008, respectively. He is currently an Associated Professor at the Department of Signal Theory and Communications, Universidad Rey Juan Carlos. His research interests include applications of statistical learning to signal processing with particular attention to cardiac signals analysis, cardiac modeling and bioelectromagnetism.

Eduardo del Arco-Fernández-Cano received the Electric and Electronic Engineering BEng in 2008 from Glyndŵr University, UK, and Telecommunication Engineering MEng in 2009 from University of Alcalá, Spain. He is currently working as an assistant professor in the Department of Signal Theory and Communications at Rey Juan Carlos University in Madrid, Spain. His research interests include Wireless Sensor Networks, wireless communications in vehicles and road traffic modeling and analysis

Javier Ramos-López received the B.Sc and M.Sc. degrees from the Polytechnic University of Madrid, Spain. Between 1992 and 1995 he cooperated in several research projects at Purdue University, Indiana, USA, working in the field of Signal Processing for Communications. He received the PhD degree on 1995. During 1996 he was Post-Doctoral Research Associate at Purdue University. Dr. Ramos received the Ericsson award to the best Ph.D. dissertation on Mobile Communications in 1996. From 1997 to 2003 Dr Ramos was associate professor at Carlos III University of Madrid. Since 2003 Dr Ramos is the Dean of the Telecommunications Engineering department at the Rey Juan Carlos University of Madrid. His present fields of research are Broadband Wireless Services and Technologies, Wireless Networks Security and distributed sensing.

Julio Ramiro Bargueño received the Physics Degree in 1991 from Autonoma University of Madrid, Spain. He received the PhD degree on 1997. He is currently working as an assistant professor in the Department of Signal Theory and Communications at Rey Juan Carlos University in Madrid, Spain. He is currently the Academic Secretary of the School of Telecommunications Engineering. His research interests include wireless sensor networks (WSN) with applications to energy efficiency.

Jesús Requena-Carrión received the Electrical Engineering and Ph.D. degrees from the University Carlos III de Madrid, Spain. Since 2006, he has been with the Department of Signal Theory and Communications, University Rey Juan Carlos, Madrid, Spain, where he is currently an Assistant Lecturer. His current research interests include the area of signal processing and computer modelling in cardiac electrophysiology.