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An Embedded Systems Course for Engineering Students Using Open-Source Platforms in Wireless Scenarios

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***Abstract*—This paper presents a case study analyzing the advantages and disadvantages of using project-based learning (PBL) combined with collaborative learning (CL) and industry best practices, integrated with information communication technologies, open-source software, and open-source hardware tools, in a specialized microcontroller and embedded systems engineering Master's course. In addition to addressing industry requirements in both contents and methodology, the course develops capabilities and competencies in problem solving, independent learning, teamwork, and technical knowledge. Since PBL methodology alone does not ensure teamwork, it was complemented with CL. Design review meetings (as described in IEC 61160), deliverables, and organizational resources were also introduced to mirror industry demands. This structure integrated course content and student academic achievement in a simulated industrial environment. The course had students build a modular management system for home appliances, implementing control software on the "Arduino" open-source platform, as well as using wireless communications. The results show that teaching, learning, and student assessment processes can be improved by using PBL with CL. In addition, the introduction of industry practices, such us peer review meetings, brings academia closer to a real-world context.**

***Index Terms*—Cooperative/collaborative learning, engineering education, IEC 61160, innovation, open-source hardware, open-source software, teaching strategies.**

I. Introduction

ENGINEERING project courses are helpful in preparing students for real-world jobs in industry [1]. Over the last decade, university education has mostly had a theoretical approach, but this does not address the current needs of real-world industry, particularly critical engineering topics such as testing, code reviews, release management, and teamwork. Moreover, advances in communications technology and the growing market for embedded devices have led to new educational programs [3], [4]. In this context, the European normalization of higher education introduced a new methodology to improve teaching techniques, which is described in the Bologna process [5], [6].

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Several works in the literature have analyzed various approaches to improving the learning process and student motivation [7], [8]. These proposals were oriented toward incorporating multidisciplinary concepts and teaching professional skills that are difficult to impart in a conventional lecture course, such as teamwork, communication capabilities, self-sufficiency, goal setting, and relevance to societal problems. They highlight the importance of a cooperative environment. Another approach is project-based learning (PBL), an effective methodology defined as *a learner-centered approach that empower learners to conduct research, integrate theory and practice, and apply knowledge and skills to develop a viable solution to a defined problem* [9]. Examples of successful PBL courses were described in [10], whose authors concluded that PBL is a successful student-centered teaching method applicable to computing science courses. Because PBL was designed based on conventional teaching methods, some problems have been encountered [11], [12]. PBL can fail in practical courses that require cooperative work, the production of deliverables, considerable feedback, and significant organizational resources [13]. The authors of [14] and [15] used PBL combined with information and communication technologies (ICTs) in their methodologies. They reported that ICT can improve the progress of engineering education, but that there is still a need for work that addresses the importance of a collaborative learning (CL) environment. Students need to derive and discuss their opinions, design their projects, and decide the outcomes in new ways. Some studies have shown that students do not acquire some necessary specific technical content, or experience many aspects of real-world industry, when simply conducting projects [16], [17]. Several proposals have tried to combine PBL with emerging tools; here, PBL is complemented with CL.

CL is an approach to improving teamwork by transforming learning groups into functioning teams. According to [18], it is characterized by the following: 1) a positive interdependence between students to foster cooperation between members of a group; 2) methods to improve oral communication among students; 3) individualized teacher evaluations (feedback) of students, group dynamics, and results; 4) motivation to acquire collaborative skills (leadership, decision making, trust building, communication, and conflict management); and 5) technical recommendations to stimulate group discussion while carrying out project tasks, to meet goals and establish effective working interactions (personal and professional). Successful examples of this are [18] and [19].

To introduce industry practices, the proposed incorporation of PBL/CL/ICT in the course required scheduled deliverables with hard deadlines; feedback from both teachers and other students, a simulated peer review process; and the use of organizational open-source resources, such as Wikis, Moodle, or file-hosting service utilities. Additionally, the methodology was implemented with an adapted approach to the IEC 61160 Design Review Standard (DRS). This standard advises on implementing design reviews to verify the design and ensure that the implementation requirements have been understood, to achieve maximal results for the design [20]. The design review is held at several milestones in the project development process, verifying that the initial requirements are being met, as well as identifying future requirements. Design review management is required as part of the design control process in order to develop products in a regulated context. According to [20], a reviewer external to the team must lead the review. In the learning context, this role could be played by the teacher or by a different group of students. In such a peer review, the other student teams and teachers act as the customer in the process. The following sections will analyze this and introduce the complete cooperative PBL (CPBL)-based home appliance system, along with new methodologies for engineers applying DRS, a new departure to be validated in this study.

II. Course Design and Implementation

This section introduces the design and implementation of the three-ECTS (European Credit Transfer System) credit course "Home Automation and Embedded Systems for Wireless Communications," compulsory for students enrolled in the Master's degree in telematics systems and computer science at Rey Juan Carlos University, Spain. New methodologies were introduced to improve the course.

A. Objectives

The curriculum content for this course is oriented toward building a wireless home appliance using an open-source development environment for smartphone applications and an open-source embedded system. Engineering students acquire new competences related to teamwork, emerging technologies, embedded systems for home appliance industry, sensing tools, monitoring tools, and wireless communication technologies.

Methodological improvements were applied and evaluated in teaching/learning activities, issues outcomes, and the assessment process by using ICTs. Open-source hardware and software technologies were used to allow students to work at home. This approach is affordable and scalable for higher numbers of students.

However, applied engineering courses for a computer science degree usually have a high student failure rate. Students need better knowledge of the opportunities offered, as well as competences demanded, by the market in embedded systems, telematics systems, home appliances, and mobile applications. Therefore, the methodology focused on the following:

- improving student understanding of theoretical concepts related to embedded systems, home appliances, communication technologies, and mobile devices related to sensor and actuator systems;
- organization and cooperative learning, using tools for two objectives: organizing tasks for each group around a project development and improving students' oral communication in their groups to solve problems and to design and propose solutions.

To ensure this, the lecturer holds assessment meetings to review the project (design review meetings, according to IEC 61160) at the start, middle, and end of the semester.

B. Student Heterogeneity

Enrolled students form a heterogeneous group in this course. Each year since 2011, the course has had approximately 15 students; some 55% had studied an engineering program combining computer science with management or multimedia technology; 20% were computer science students with hardware and software knowledge; 15% had studied electrical engineering; and 10% were business administration and management students with previous knowledge of computer science. The average age was between 23 and 32 years old. On average, there were two female students per year (one in computer science and one in telecommunication engineering). No differences were detected between male and female students in the final evaluation, maybe because they had had similar backgrounds (telecommunications and computer science engineering) and had acquired the same knowledge in the course.

Student background was measured at the beginning of the course with pretests, which were marked out of 5. The first group (computer science and telecommunications) scored an average of 1.5 in hardware and sensors and 2.5 in communication. The second group (electrical engineering) scored an average of 3 for hardware and sensors and 1.75 for communication. The poorest group was the third (business administration and management with previous knowledge in computer science), who scored 0.25 for hardware and sensors and 0.5 for communication. On the most recent course, only two students had any knowledge of mobile applications (just enough to make a simple application). In all the offerings, only three students, on average, knew of project-based methodology. This heterogeneity posed a significant challenge in teaching the course, if all students, whatever their starting point, were to attain the same knowledge level at the end of the course. The proposed methodology was therefore adapted to avoid obstacles for the students and to allow each of them to develop their projects in a similar way.

C. CPBL Methodology and Tools

CPBL methodology was followed in designing this course. The course components were the learning activities and the project milestones in the laboratory. Online tools were adopted to facilitate students' teamwork in sharing content and resources, as well as their collaborative identification of each project milestone. These tools promoted the exchange of opinions, documents, and feedback to facilitate the self-work required for teamwork. Interactive teaching tools such as Moodle were used. Some seminars were oriented around using file-hosting services such as Dropbox—indeed, the interactive teaching tools were integrated into the file-hosting services, with the objective being to facilitate the distribution of contents, deliverables, and milestones.

Industry professionals who had taken the course previously gave several seminars on open-source and open-hardware tools for learning activities that had a very positive impact on students, because the former students' experience illustrated that the course content was closely correlated to industry demands.

For the laboratory activities, students worked in teams of three, using open-source hardware and open-source software development kits to carry out the project with deliverables and milestones consistent with design review methodology. The students in each team had different backgrounds; this heterogeneity added complexity, but better simulated the real-world situation, where coworkers have varying backgrounds.

Students were given a manual of recommendations for teamwork; this gave three kinds of roles in a team: leader, designer, and developer. Each team member took a different one of these roles for each project deliverable. The deliverables were presentations, which were created using open-source software tools, and videos the students recorded about the various deliverables, explaining their functionality, problems, and solutions. According to the scheduled design review meetings, each group delivered reports and the results of the deliverables. The other groups and the teachers reviewed these documents following IEC 61160 DRS. The team discussions among students were very important because they learned to craft their positions and learn from their failures.

The research instruments used to collect data were questionnaires (oral and written) and development of the final project. This collection of data focuses on the factors explained in [15]: background, course content, Master's content, learning materials, assessment, and evaluation using DRS.

D. Course Content

The course schedule and content, which are designed to meet the goals of the study, are shown in Table I. Each block introduces new concepts sequentially. The lectures have four blocks, and the laboratory has three blocks, each crafted to help students design and implement the final system. Each block is related to the previous block. These blocks are designed based on the design review meeting methodology, by correcting or incorporating in a block issues detected in the previous design review. By learning the course content and following CPBL methodology and the design review meetings concept, students can work toward the final project while acquiring hardware and software skills. The following section discusses the practical component: the development of a complete system that manages and monitors lights and air conditioning using wireless communications.

TABLE I
SCHEDULING AND CONTENTS FOR THE COURSE

Contents	Tools	Time
Master's classes		
Block I Home Appliances.	Moodle.	120'
Block II Architectures. Sensor, Actuators and Signal conditioning.	Moodle. Seminar about Sensor scenarios.	90'
Block III Embedded System, Microcontroller	Moodle. Seminar of Arduino solutions and programming environment.	120'
Block IV Wireless Technologies. Protocol for home appliances Integrating ICTs in home appliances.	Moodle. Seminar about home appliances and ICTs.	150'
Practical		
Block I Design of a first home appliance. Design Protocol	Moodle. Seminar of Simulation program for Arduino. Arduino SDK	240'
Block II Advanced Arduino Design a second board Implemented final design.	Moodle and Dropbox. Examples, Simulation Board.	180'
Block III The final Smartphone Application. Test the Android application with the home appliance system.	Moodle and Dropbox. Seminars of SDK.	300'
Assessment of theoretical concepts. Explanation of the final project.	IEC-61160	120'

E. Assessment

The course's assessment process follows CPBL methodology, with the students' final grade being the result of different deliverables over the course, so students are evaluated throughout their learning. These deliverables correspond with the various tasks explained earlier and are evaluated by the design review meeting methodology, an oral presentation to assess student soft skills, and a final test.

1) Self-Assessment: Students have to report upon their own performance, with an appropriate rationale, in every deliverable assessment. As a result, they were aware of their individual background limitations and their progress, increasing the teacher–student feedback.

2) Peer Assessment: Design Review Meetings: Students play an important peer assessment role in this methodology. First, they evaluate their self-participation in the design review meeting methodology, their incorporation of this methodology, the oral communication in the discussion and definition of requirements, and the state of their assigned tasks at each milestone of the project. Second, they evaluate the same items with respect to their teammates. Third, they evaluate the other student groups based on their final oral presentations. These oral presentations cover the groups' project design, meeting of requirements, accomplishment of milestones, problems encountered, and final solution with a live demonstration of a real home appliance system. Moreover, the groups are required to explain each member's role and the results of the design review meetings. All students are required to complete a rubric evaluating other groups' performance. The group who gets the best peer evaluation receives a bonus in the final course assessment.

3) Teacher Assessment: The project milestones are explained here. Each milestone has a deadline that students must meet to achieve a good evaluation (high or very high). The milestones have to be met as a group; thus, the group needs to organize their tasks, discuss the responsibilities or problems, and so on. This study was designed to develop the students' ability to work in a real environment, which can include people who do not complete tasks or even like to collaborate. The objective was to stimulate participation and encourage taking on responsibility to avoid potential problems. In keeping with the design review meetings methodology, the teacher conducts several interviews and uses the results in the final assessment.

At the end of the course, students complete an individual survey rating their skills acquired from lectures and in hardware and software content. Results from a previous iteration of this course will be presented in Section IV.

4) Final Grading: The final assessment is on a 0%–100% scale; 50% or above is a passing grade. The final grade is a numeric grade, from 1 to 10, arrived at by summing weighted assessment percentages, as follows.

- 60%—Practical assessment. As a result of the CPBL process, the teacher-assessed grades of the various deliverables constitute the main contribution to the final grade.
- 20%—Oral presentation assessment. Soft skills are an important part of an individual's ability to succeed in a career. This includes the students' peer assessment (see Section II-E2) (10%). Teachers assess (10%) the same points as the students but also take into account how the teams achieved the objectives and their level of success. This assessment includes the grading of the final report.
- 20%—Final test. This is offered through the Moodle e-learning software platform as a multiple-choice test, including One-Best-Answer and True/False questions. Multiple-choice questions test several levels of learning and the student's ability to integrate information.

III. Definition of Project Milestones

As described earlier, students develop a home appliance system consisting of a smartphone application (Android) and an embedded system (based on Arduino) with wireless communication, based on open-source software and hardware, respectively. The objective is to allow students to work in the laboratory or at home at no cost.

Each group of students is given different requirements and a presentation of the problem by the teacher, who explains the projects' materials and components, as well as the compulsory and optional milestones to build the final project. At each milestone, groups must provide reports and give a demonstration to show the current functionality of their system, using specific tools such as Moodle, as indicated earlier.

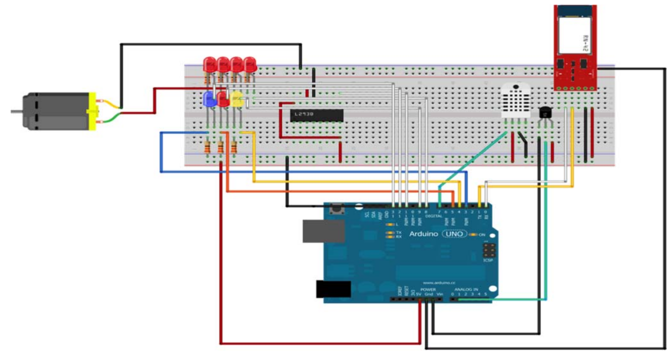

Fig. 1. Modules for the home appliance system using an "Arduino Uno Board" and a Bluetooth module such as Bluegiga X11.

A. Block 1: Arduino

The home appliance system is conceived to have a star topology, where the Arduino platform acts as the master device at home. "Arduino UNO" was chosen. Three milestones are evaluated. First, the students have to design and make the connections on the Arduino prototyping board using a 3.7-V battery to power up the system, a fan (simulating an air conditioning system), and several LEDs (simulating lights). The system will simulate a house with at least four different rooms: bedroom, bathroom, living room, and kitchen. The teacher checks this work in a design review meeting.

Second, the students have to apply their theoretical knowledge of embedded systems acquired in class and develop the code to manage the system. They can simulate this process in a virtual Arduino using Fritzing, an open-source software initiative that allows designers and researchers to work creatively with interactive electronics.

Third, the teacher reviews the code before uploading it to the Arduino platform, checking that this block works properly.

B. Block 2: Advanced Arduino

Next, students have to design and implement a new scheme for the home appliance system to switch on/off the simulated lights (LEDs), read information from sensors, and manage air-conditioning modules (servos and ventilators) with wireless communication using a Bluetooth chip. Fig. 1 shows an example of the different elements, using open hardware for the project. This is an open design to meet the various project tasks. Obviously, students can use other microcontrollers, Bluetooth modules, and sensors.

First, students have to connect the new hardware: LEDs, an analog temperature sensor (LM35) or a digital temperature sensor (sHT11), a fan (a dc motor using pulsewidth modulation), and a Bluetooth module using a prototyping board. They have to connect different LEDs to simulate different rooms in a house (bedroom, bathroom, living room, and kitchen). The ventilator will run based on the data acquired from sensors. The students will present the new board design to the teacher.

Second, they will use a wireless technology to manage the Bluetooth system. They need to know how serial port profile works in Bluetooth. This profile allows the exchange of information using Bluetooth connection between devices.

Third, students develop new code for Arduino to manage the new components. At this milestone, students are evaluated on their knowledge of managing analog/digital interfaces and interrupt routines in embedded systems, as well as on their Bluetooth communications knowledge. Therefore, this block is quite complex and complete. The design, code, and development must work properly and meet requirements.

Students can improve their grade with an optional phase that includes a SANWA SRM-102 servo. The board will have two analog sensors to acquire the temperature from the environment. The servo and dc motor work based on the data received from sensors. Students should follow the datasheet instructions for the servo and the dc motor to develop the code to manage both of them. They will integrate the developed Bluetooth system with the dc motor, servo, and sensor management.

C. Block 3: Android/PhoneGAP

In this block, the students have to design and develop a complete smartphone application to manage the home appliance system, using Android or PhoneGAP SDK. They are given examples in lectures and seminars.

First, the students need to design the interface of the mobile application with different functionalities, which is separated into three screens: connection to the system, illumination management, and temperature management.

Second, they have to develop the functionality for the Bluetooth communication. At the end of this block, students will present the home appliance system and the management using the mobile application. This presentation consists of an oral presentation of their work, a video demonstration, and a live demonstration.

IV. Results

A. Final Grades

To evaluate the new methodology, this section compares the students' academic results with data from previous course years. Results are based on the grades and feedback of 15 enrolled students in each of three academic years: 2011 and 2012 (traditional method) and 2013 and 2014 (methodology described here). Due to the different student backgrounds, the CPBL process shows an increased cooperation in completing various tasks and developing teamwork and technical skills to achieve their objectives. Additionally, as different groups of students may adopt different plans to complete the project, other groups can benefit from these different points of view, increasing their overall knowledge.

Fig. 2 shows how the 2012–2013 and 2013–2014 final grades increased compared with 2011–2013. Final grades are generally high, trending toward first class (> 7.0). The grade distribution for students in the 2011–2012 course was similar to that in [1] and [8]. This suggests that the methodology led to an improvement of academic results. In contrast to [18] and [19], 93.5% of students had an 8.5–10 in the evaluation, and everyone passed the course.

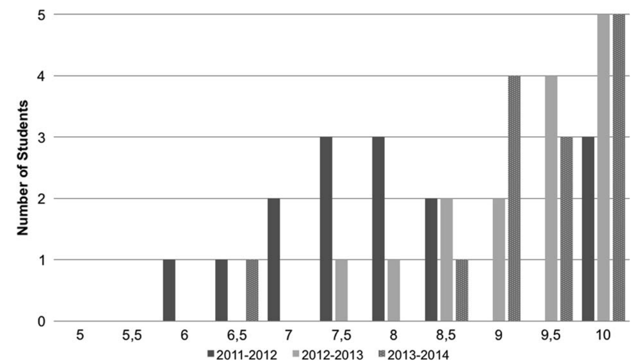

Fig. 2. Bar chart comparing the final grades of the last three course offerings. The maximum grade is 10, and the passing grade is 5.

In one year under the new methodology, a female student, with a business administration background, received a final grade of 6.5 (two points less than most students). She had acquired the necessary knowledge with this methodology; but here, score suffered because she required additional teacher assistance and tutorials, approximately 3 h more than the average.

These results, as well as a comparison with previous research described in Section I, demonstrate that the introduction of CPBL and the peer review meeting methodologies improve the teaching/learning process. This process allowed more content to be taught and more knowledge to be acquired. The increased student involvement in the course improved the final grade by up to 10%–20%.

B. Methodology Assessment

To measure the course's potential as an educational resource, student feedback was obtained through a final course survey and the institutional Teaching Evaluation Questionnaire (TEQ). Students were asked about the delivery, assessment, content, quality of demonstration, and teaching received. These surveys used the typical five-level Likert scale [21] to measure the level of agreement or disagreement.

For this process, the teachers asked about student satisfaction with learning resources, delivery of hardware and software skills and of sensor and appliance systems skills, the CPBL methodology, the design review meetings methodology and interview, and the overall teaching–learning and assessment processes. This was compared with results from before the methodology was introduced. Figs. 3 and 4 show the final course survey, which was administered by the university, that measures valuable psychometric characteristics such as reliability, validity, and internal consistency, as well as takes into account the role of the teacher in the course development.

Fig. 3 shows the average rating with and without the proposed methodology, indicating that students are very satisfied with the acquired knowledge in the last two courses. Fig. 4 shows the variance of the agreement with the TEQ. This demonstrates that despite the heterogeneity described in Section II-B, the students' level of acquired knowledge is

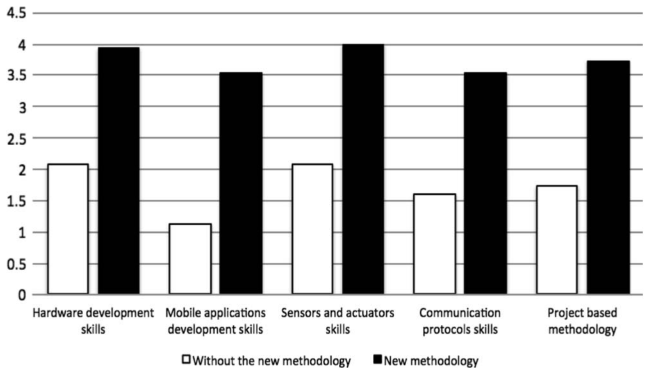

Fig. 3. Level of agreement with items on the institutional TEQ, asking to what extent the skills had been acquired (on a five-point scale).

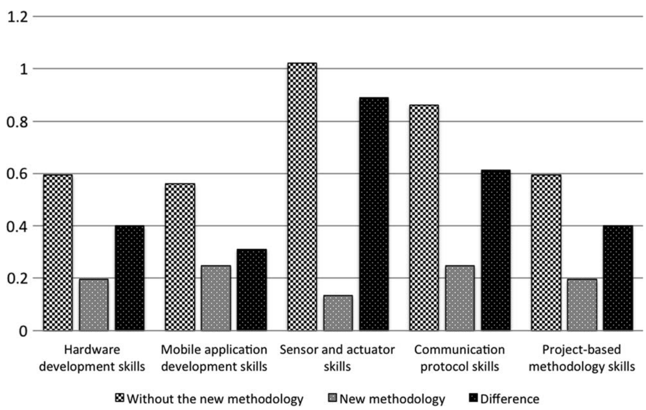

Fig. 4. Variance of the evaluation related to the old and new methodologies.

similar. The variance for each item (hardware, mobile, sensors, communications) is very similar under the proposed methodology (< 0.25).

Moreover, in an individual questionnaire administered at the end of the course, the students commented that they were motivated to find a job where they could apply their newly acquired course content and work methodology. They appreciated the CPBL process, as opposed to traditional lecture and written-exam-oriented courses. Additionally, they felt they had acquired useful technical and soft skills for their future careers, preferring this approach to laboratories in which they are given step-by-step instructions to perform an experiment, requiring little thought or insight on their part.

Some students had more difficulties with the CPBL process because of their backgrounds. However, they reported strong satisfaction with this model despite finding the modules demanding. They emphasized the great benefit of being able to work on their project outside of laboratory time, leveraging the benefits of solving problems in laboratory sessions. A survey of satisfaction with the assessment process and the course overall yielded an average of 4.13 and 4.6, respectively, out of 5, with a variance of 0.25 points. Therefore, students were mostly of similar opinion. The students also reported being interested in an elective follow-up course focusing on embedded systems and/or smartphone programming. Of the students in the most recent course offering, 95% recommended this course to others.

V. Conclusion

This paper has reported the successful combination of CPBL plus design review meetings methodology with ICTs, open-source software, and open-source hardware in an engineering course. Design review meetings, as per IEC 61160, deliverables, and organizational resources, were introduced to meet industry demand. Students worked collaboratively throughout the course and appreciated the potential of this work methodology for their future jobs. Coursework here was distinct from that of their previous courses in that it incorporated oral communications, group discussion, and sharing of team responsibilities. In this course, students developed a real scenario for home appliances with open-source tools, smartphones, and wireless communications. The students had to apply theoretical concepts to acquisition, processing, and wireless communication technologies. The course promotes capabilities and competencies in problem solving, independent learning, teamwork, and acquisition of technical knowledge, all taking into account industry demands in both content and methodology. Course content is practically oriented to address industry demands and prepare students for professional requirements. This paper concludes that the teaching, learning, and evaluation processes could be improved using CPBL environments and the design review meetings format.

In terms of teamwork for the final project and the design review meetings, students felt that cooperation helped them to learn. They reported challenges with the amount of time required to work together, their differing backgrounds, and the noise level during class sessions. According to the survey results, they understood the importance of discipline and organization when working in nonheterogeneous teams.

The proposed methodology and the project milestones to build a real home appliance system in groups are adapted to address industrial demands, to integrate CPBL and ICTs, and to improve capability in a varied group. The initiative has twice won awards based on its success and has recently been published as an open course for students from other universities. The methodology is now being applied to other courses for telecommunication engineers.

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