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Playing LEGO Mindstorms® while Learning Remote Sensing*

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An experience developed in the frame of a graduate level course in Electrical Engineering is introduced in this paper. The use of LEGO Mindstorms indexer and sensors appears to solve the needing of cheap and interactive experimental work to learn about sensors along a topic on Remote Sensing, involving the students in a play that becomes a strong learning tool. The evaluation methodology consisted in a test and a survey. The outcomes show a large satisfaction level among students, but also a correct labour in the cognitive dimension.

Keywords: learning through play; affective; cognitive

1. Introduction

The subject 'Remote Sensing' involves the exploration of the Earth surface, atmosphere, and Space; the sensor functionality and technology; and even the processing of satellite images. The design of active learning strategies for such subjects appears to be something difficult, mainly due to the large economic effort needed to construct each experimental part of the topic. However, the implementation of active learning methodologies results largely suitable, since these methods facilitate students to learn both Engineering processes and conceptual knowledge.

The contents of the course on 'Remote Sensing', offered in the last semester of a five-year degree on Telecommunication Engineering, have been designed according to a classical combination of theoretical and practical lessons. Each part covers 3 ECTS (European Credit Transfer System units), which indicates that the experimental part of the topic has the same importance as the theory in the mind of the curricula designers. So, a correct balancing in the methodology of theory and experiments is expected, and the course has to be carefully designed.

A case example of the learning-through-play theory has been applied taken into account the previously exposed environment. Teaching of a 'Remote Sensing' course usually offers problems to deploy cost-effective and attractive lab work: though it is possible to analyse different satellite taken images, undergraduate students do not commonly have access to an actual satellite on-board sensor.

In this situation, the objective was to design attractive practices to learn about a specific area of the course, the sensors, forcing the students to play (and to play with very friendly toys!) in order to reach the education objectives. During the theoretical lessons, sensors and related concepts are explained and solutions to some problems are shown on blackboard. This part of the subject follows a teacher-centred methodology supported by slides that are actually provided to the students via an online educational platform based on the Claroline system [1–2]. Later on, in the laboratory, practical exercises are developed. Up to the year 2008/2009, the available material was spare, mainly due to the large cost of educational material. Some tailor made systems tried to be built, but this option was also largely expensive for a growing student group size: this course experienced an enrolment of 80 students last year.

Students were grouped in couples, and later assigned to a lab group controlled by a teacher. Management of LEGO Mindstorms kits was proposed. This opens the possibility of performing some experiments on robots that obtain data from their environment by means of sensors. Thus, the students had fun during the sessions: it is difficult to find any Engineering student who had not played with construction blocks in his childhood, or who does not like to program a complete system to perform some activity. But, what is more important, the students also learn a lot about different kind of sensors. Also, they experience the need of sensor calibration to obtain the wanted response from the robot: only when the robot understands the collected data, and this data (the electric values the robot receives) correspond to actual phenomena in the robot's environment, the robot will act as the programmer expects. If the calibration is not correctly defined, the robot reaction appears to be wrong. But what it is happening is that the robot is not sensing what the observer is detecting because

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its sensors are providing erroneous information on the environment.

After the experience with this learning through play activity, the teachers are sure that simple experimental tests can facilitate the acquisition of important concepts that students will need to use and apply. And they acquire this knowledge while they play!

The explanation of the experience is covered by this paper, which consists of seven sections in addition to this introduction. The second section contains a brief description of the topic 'Remote Sensing' in the current curricula of Telecommunication Engineering, as well as the insertion of such contents in the new curricula, adapted to the European Higher Education Area (EHEA) [3]. The third section trades with the different strategies of active learning techniques, including the learning through play. The fourth section is devoted to the learning objectives of the introduced experience, which is described in the fifth section. Whereas the results are the topic of the sixth section, the evaluation of the impact on students learning is contained in the seventh. Finally, the conclusions of the work and the future application of the experience are the main topics of the eighth section.

2. The topic 'Remote Sensing'

For the last ten years, the School of Telecommunication Engineering at the Universidade de Vigo has been offering a course on 'Remote Sensing'. It is placed in the last semester of the Telecommunication Engineering degree, as an ending learning element. This degree curriculum extends along 5 years. The course is defined as optional and it is usually taken by students following an itinerary on Radio Communications, but also by Computer Science or Electronics students. This background leads to an essentially descriptive topic, based on the fundamental concepts on electronics, signal processing and radio the students have acquired in previous semesters courses.

Currently, the Universidade de Vigo, as well as all Spanish and most European Universities, is involved in a process to converge to the EHEA and a new curriculum for the topic has been defined. The new Graduate degree on Telecommunication Technologies Engineering incorporates an optional course on 'Remote Sensing'. This new course is offered in the seventh of eight semesters. The contents of this course would be an evolution of the currently taught in the in-extinction formative program. Accordingly, the learning material developed and tested during the extinction period in the old topic is expected to be useful in the implementation of the new curricula.

The 'Remote Sensing' course is intended as an introduction to the multiple areas and applications of the art of collecting data, related to places or phenomena, by using sensors far from the element under observation. Such an objective covers from spatial observation to medical non-invasive devices, going through Earth surface research, meteorology surveillance, target recognition, and so on. Along the semester, the students are expected to learn about applications of Remote Sensing, but also about the involved technologies.

The course work charge is currently defined in 6 ECTS, and it is designed in two sections: 3 ECTS for theoretical lessons, in classroom, and the other 3 ECTS for experimental work, within a laboratory. The academic organisation leads to force the students to effectively attend 26 hours of classroom sessions, and 14 hours of lab sessions. These lab sessions can be PC-based simulations or hardware activities. The experience of teaching and coordinating this course for the last 10 years indicates that the students prefer those activities where they have to manage a device, or to perform some measurements, to those where they have to process data in a computer. The first years of teaching this topic, due to economic limitations, the lab sessions were based on managing software, being focused on processing of satellite images of the Earth surface, both Landsat and meteorological data.

The first improvement of the lab duties was performed after acquiring of an infrared thermal camera, which allows the students to learn about the use of such device as well as to test the different applications of remote sensing in the thermal spectrum. However, some contents such as sensors and its calibration were only taught in classroom lessons, as the complexity and price of the electronic elements were out of the scope of a descriptive topic (the simplest costs over 3,000 €). This lack of experimentalism was solved during the 2008/2009 academic season. Then a new element was introduced in the laboratory: a commercial kit of robots (LEGO Mindstorms®), which individual cost was under 300 €.

Although the elements are initially designed to play for kids over 10 years, 22 years old students were enthusiastically involved in the activity. Clearly, fun is not opposite to learn. The staff verified that, after this activity, the students learn more than previous years about sensors and their calibration, as they demonstrated in the exams of the course.

3. Active learning

Traditionally, the most extended teaching method used in a high number of Colleges and Universities is the classroom tutorial lesson. However, the work on different pedagogical strategies suggests to focus on active learning, experimentation, or research guided by teachers. These new forms of knowledge acquisition have been clearly stated and demonstrated during the last two decades [4–9]. Most of the instructors agree that students learn more, and what is more important, they learn better, when they do experiments than when they just listen to the professor. But this fact is commonly crashed on a wall due to the additional effort that changing from classroom lecture to active learning would require. The effort in terms of time is obvious. The development of new material involves additional work, compared to the use of last year material, or even to the improvement and actualization of previous material. But the effort required to the instructor grows also in terms of concentration. During a classroom lecture, the teacher controls the timing, the organization, the moment for asking or for working; during an active learning session, the progress of the experience depends more on the students, and the instructor has to adapt the evolution to the rhythm of his pupils. The teacher should maintain the students focused on the learning objective. He must answer questions as they arise during the experience that perhaps he had never thought about. And he also has to keep the rigor expected in a higher education curriculum, among other activities.

In many cases, the instructors need an external stimulus to be involved in the development of material that incorporates active learning experiences, which is a challenge for the instructors that are not usually encouraged to face this step. Among other reasons, the EHEA process has established the University and studies structures; but not the training methodologies that should consider the use of active methodologies to improve the student learning process [10–13]. However, the wind of change that impulses the EHEA convergence would be a good opportunity to incorporate new methodologies in parallel to new topics and contents.

Two proposals to incorporate active learning teaching are 'learning by doing' and 'learning through play'. We have selected them among other ones due to the suitability to our goals and contents.

- Learning by doing. The learning based on the experience, experiential, factual, 'learning by doing' or 'hands-on learning' is generally framed in the active learning methodologies. This supposes to encourage people to discover by themselves the principles of operation of the systems, processes, etc. through the experimentation and the exploration [14–18]. Some of the laboratory activities in the topic 'Remote Sensing' could be ascribed in this category, as the operation of an infrared thermal camera to obtain thermal images.
- Learning through play. Students must learn the fundamental concepts and the necessary skills to apply them effectively in a game-based experience. This methodology has been widely applied in computational and engineering teaching field [19–21] showing a large level of satisfaction, and becoming also effective at the cognitive level. The activity presented in this paper, the use of LEGO Mindstorms kits to learn about remote sensors, is clearly endorsed in this group of methodologies.

4. Learning objectives

Some concerns arise among instructors when teaching the 'Remote Sensing' course. Are some important and basic concepts effectively transmitted to the students? Do students acquire the knowledge the teachers look for? Some of these doubts came from the previous experience on teaching such course. For example, within the area of sensor technology and the use of actual devices: the calibration concept. In many cases, the concept of calibrating a sensor, and even more, the key importance of calibrating a sensor, is not easy to transmit to students that are used to manage a lot of processing techniques, but not an actual measurement situation. In previous years, the learners studied the theoretical aspects of the sensors, and most of them remembered the concepts the day of the exam! But when asking in a test about the calibration interest: why you need to calibrate a sensor?, or how is the process to calibrate a sensor?, the problems appear . . . and this is not expected in persons that are going to be in front of complex engineering problems in few months!

The main objective of the activity was, consequently, to achieve the students to understand why a sensor does not work correctly when its calibration is not properly done. And the experience shows that this concept is more clearly acquired when it is experienced than when it is just discussed in the context of a lecture.

Besides, the experience allows students to develop communication skills and collaborative competences, which are part of the competences required for the new EHEA Graduate degrees.

5. The experience

Learning by doing or through playing experiences based on hardware activities imply the use of equipment that, sometimes, is not covered by the general purpose instrumentation. Trying to jump over this problem, two different practical sessions have been designed, regarding the concepts of linear tracking and sensors operation showed in the theoretical lessons. These practices were based on a commercial kit of robots (LEGO Mindstorms®). The kit consists of various accessories: an indexer, motors, and infrared sensors. Well, and also a lot of LEGO bricks! Commercial software is also included in the kit to program the main parameters for the robot's operation, such as the movement direction, the speed, the sensor thresholds and the execution time. Such a toy is obviously an evolution of those directed to five-year old children, but in fact it is oriented to people younger than our University students. However, some of the features of the sensors in the kit could be very adequate to the learning objectives we pursue.

The strategy of the experiment followed the three phases indicated in [22] for another edutainment (education through entertainment) experience:

(1) Planning and building of the artefact, related to the problem identification and the objective definition, the collection and production of ideas, as well as the problem conceptualization. During the building and manipulation phases, a fundamental role was exercised by the perceptive and behavioural functions.
(2) Behavioural programming, in which students identified problems, hypothesized and then they applied solution strategies.
(3) Testing, when the students tried the artefact and decided on the need to go back to the building phase, to the programming phase, to both, or rather to search for new ideas.

The students were organised in groups of up to five members, and a set of tasks were proposed to each group. The final objective of the practical session is to build a wheel engineered robot, with the aim of tracking a black line on the floor.

First, a wheeled robot able to move forward and backward, to turn left and right, to stop and go . . . should be built. This stage involves all the team, trying to develop the perceptive functions of the students in a task that is not common for electrical engineering undergraduates.

After this point, 'Remote Sensing' concepts appear: the robot should perform different movements as a response to different situations. In other words, it is desired that the robot senses the environment and reacts to such environment. We begin presenting the different sensors in the kit: sound, colour, infrared, switch, and then proposing to program simple codes to control each of them individually. The final objective is to ask the robot to follow a black line on the floor, and to perform a right test! The robot has to move along the room, avoiding crashing the furniture or walls, and tracking the marked path. In particular, the threshold level parameter of the colour sensor control block in the indexer program is used to distinguish one colour from another on the floor, in order to detect the presence of the path. An infrared distance sensor is used to avoid the crashing events. The photo at Fig. 1 shows a robot moving towards the black line during the test of the program by a group of students.

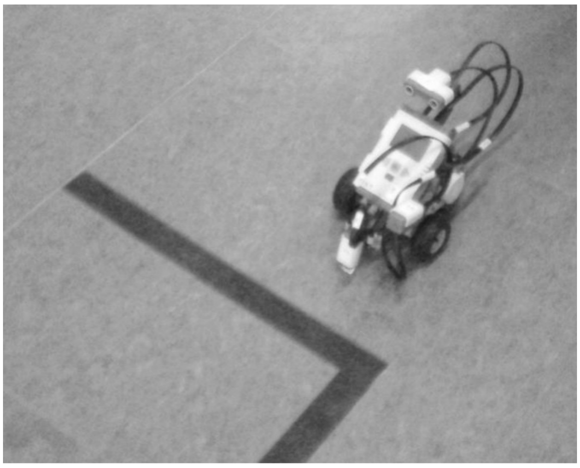

Fig. 1. The robot moves towards the black line in the ground.

Over the programming troubles, some technologic problems show up during this task: only if the sensor is well calibrated the robot would to act as expected. This could be explained in other words. The colour sensor converts the received light into a voltage level, following a code: depending on the colour, it assigns a voltage level. The program at the indexer could order some action as a function of the voltage received from the sensor, not yet of the colour measured. This means that the program and the sensor must manage the same 'colour table', because in other case the action performed by the robot would not correspond to the detected colour. The environment conditions also have an important influence in the colour detection by the sensor, which means that the sensor has to be calibrated at each specific environment to perform its task.

The students receive a wrongly calibrated sensor in order to be forced to detect the problem and to look for a solution. Thus, they notice the importance of the calibration, because only after doing that process the robot is going to perform the requested tracking. Once they solve the calibration, other programming problems could appear, but at least they are sure their indexer is well interpreting the received data from the sensors. The picture at Fig. 2 shows a robot moving along the black line, after solving the calibration problems.

Most students decided to voluntarily extend the requirements of the practice, forcing the robot to perform a more complex activity: a ball is placed

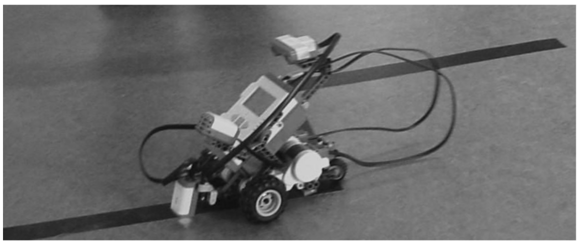

Fig. 2. The robot moves along the black line in the ground.

along the black line and the robot, while tracking the black line, has to detect the ball and to shoot it out of his path. The picture at Fig. 3 shows a robot shooting the ball far from the black line.

6. Analysis of qualitative impact of the experience

During the execution of the practices, we detected the same three different typologies of work subdivision as reported in [22]:

(1) The first one was a ‘collaborative activity’, in which each member adopted a role in the building work and all of them participated in the programming of the robot.
(2) The second typology corresponds to an ‘all at all activity’: members that did not adopt a specific task in building and programming the robot.
(3) The third option was a ‘leaded work’: each member adopted a role in building and programming the robot and a leader supervised the work.

Independently of the followed strategy, the groups of students seem to be very interested in reaching the objective, and they appear to be in depth involved in the assigned task. We then found that the use of the toy kit stimulated students to explore their own knowledge in a critical way, and to share it within the group, which means that the objective of the experience has been largely reached.

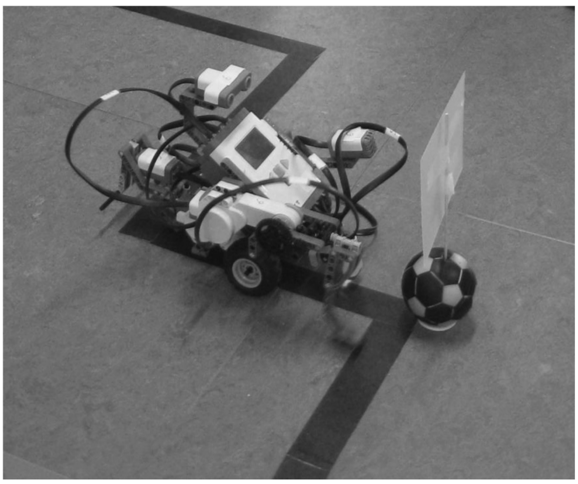

Fig. 3. The robot shoots the ball out of the black line.

The qualitative impact on students learning may be considered, as a consequence, completely positive, as they could work in a friendly environment, playing with a funny toy, and getting some knowledge and skills required within the course of ‘Remote Sensing’ and, what is more important, for their professional career development. The quantitative impact of the experience is analysed in the following section.

7. Evaluation of the impact on students learning

Another, but not less important, aspect to be considered along the development of this kind of learning is the way of evaluating the acquisition of knowledge [23]. It is essential to collect information in the cognitive and in the affective dimension. This information has to be analyzed to evaluate a classical trade-off: the satisfaction level and the effective cognitive learning.

The satisfaction level of the experience can be evaluated by an innovative method based on online surveys provided through a web educational platform that uses the open source eLearning and eWorking platform Claroline [1–2]. The enthusiastic response of the students moves us to feel that the experience was satisfactory for the students, at least in the affective dimension. Consequently, we thought that the communication skills, as the ability to work in groups and to share their personal knowledge to get a final group product, could be considered as acquired by the attendants. Some improvements could be incorporated to the experience, as allowing the students to introduce larger innovations in the final product, instead of a mainly guided exercise as we proposed along the experience.

A set of questions have been included in the individual final course exam in order to evaluate the cognitive level. The answers to the questions related to sensors are analysed in the following paragraphs.

Among the ten questions of the final exam (each question pounded 10 over 100), one of them was directly related to the practical experience with LEGO robots, asking for aspects of the calibration of a sensor, and a second question was focused on some theoretical aspects of sensors, in particular on resolution concepts.

Each question was evaluated over 10 points, which represents 10% of the total qualification of the ‘Remote Sensing’ course. Focusing on the ques-

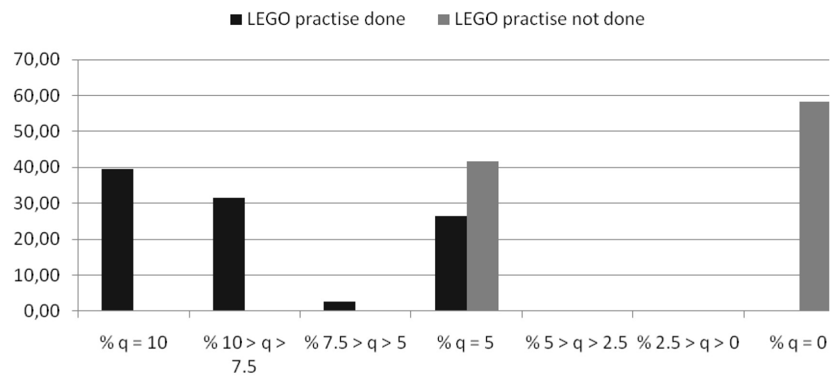

Fig. 4. Percentage of qualifications of question about the calibration (over 10) grouped in bands.

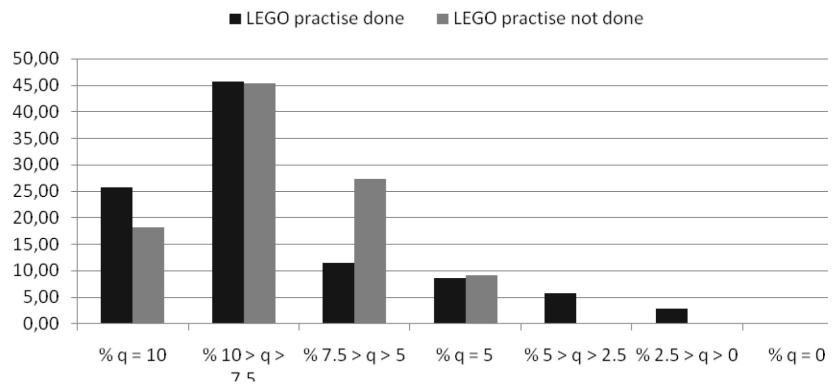

Fig. 5. Percentage of qualifications of question about sensor resolution (over 10) grouped in bands.

tion about calibration, the students who participated in the experience obtained largely better results than those who did not: all of them got more than 5 points, and more than 70 % obtained 7 points or more. Whereas, 58% among those students who did not attend the experience got 0 point and the maximum qualification was 5 points, which matches the minimum qualification among the students attending the lab. In fact, the mean marks of each group of students were 7.9 for those who did the practice and 2.1 for those who did not. Fig. 4 depicts the distribution of the qualifications of the question on the LEGO practise, analysing separately both groups of students. These results indicate that the students involved in the experience objectively learned more about the calibration process than those who did not attend the lab sessions.

Another question of the exam was focused on sensor resolution, which was taught in classroom tutorial lessons, and the results appear to be better balanced: the mean marks were 7.82 for students who attend the experience and 7.81 for those who did not. The distribution of the marks can be observed at Fig. 5, whose analysis indicates that no differences exist between both groups when dealing with theoretical concepts.

The previously analyzed results of that pair of questions lead to interesting conclusions. There are no differences between results obtained by both groups of students in terms of the theoretical question. No more than studying what the professor taught during the lessons at the classroom is needed to answer this question. And so, the results are similar for both groups, as the active learning

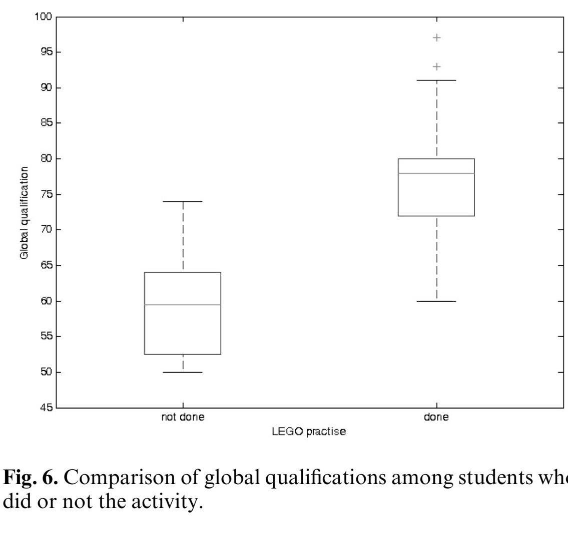

Fig. 6. Comparison of global qualifications among students who did or not the activity.

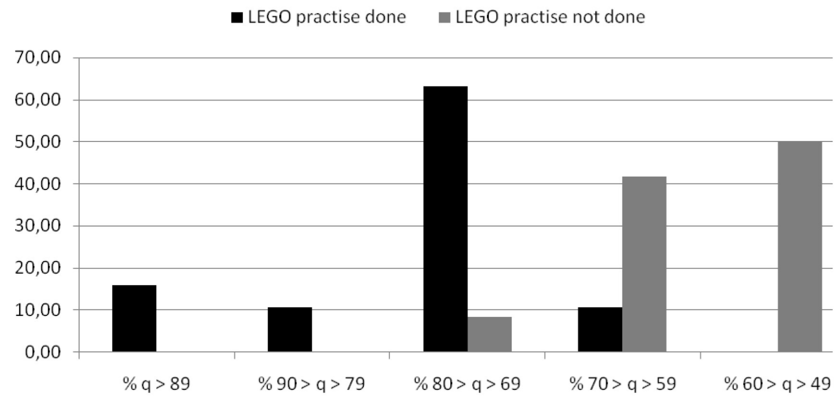

Fig. 7. Percentage of global qualifications (over 100) grouped in bands.

experience did not put emphasis in the contents of the question. However, the practical question was focused on the process of calibrating a sensor. The students attending the active session appears to learn more than those whose knowledge on the topic is limited to what the instructor taught during the classroom lessons. The difference in terms of cognitive results is clearly highlighted, with an important improvement in the qualifications by the attendants group.

If we focus on the final results of the course on 'Remote Sensing', a total of 50 students passed the final exam. Among them, 38 had done the practice with the LEGO kit, and 12 had not. The final qualifications of the students present a mean value of 72.8 over 100; being 77.1 the mean among the students who participated in the active learning proposal and 59.3 that for those not involved in the experience. Fig. 6 depicts, by means of a box-plot representation, the global qualifications obtained by the students in the course 'Remote Sensing'. The results appear to be clearly better among the students who were involved in the experience, what could be explained by the learning skills acquired during the practice.

Those final qualifications have been also classified in five bands, grouped by decades: 50s, 60s, 70s, 80s and 90s over 100. The percentage of qualifications at each band is presented in Fig. 7, with a separate analysis for those students that attended the active learning experience and those who did not. The final mark was clearly better for the first group, with 15.79% of students over 90, and 10.53% between 80 and 89, whereas none students obtained more than 79 over 100 among those not following the experience.

The pilot experience showed a large level of enthusiasm and satisfactory feeling among students. So, the yearly surveys on every course demonstrated, for the 'Remote Sensing' one, a good performance in the affective dimension. Moreover, the good results also achieved in the cognitive dimension encouraged the teachers to repeat the experience next year trying to introduce some novelties. A team competition would be clearly a possibility offered thanks to the developed and tested methodology and the available material, as well as the experience acquired by the teachers.

8. Conclusions

The introduction of learning through play activity, based on a commercial toy kit by LEGO Mindstorms®, in a classical course on 'Remote Sensing' has been presented and analysed along this paper.

The main conclusion may be that simple experimental tests can facilitate the acquisition of more important concepts that students will need to use and apply as professional engineers after graduation.

We presented the methodology developed and the material needed to carry out a practical session within a course on 'Remote Sensing', in particular for concepts related to sensors. The pilot experience showed a large level of enthusiasm and satisfactory feeling among students.

The evaluation of the experience indicates that students that followed the activity obtained better results in the final exam than those not involved. In fact, the mean marks of each group of students were 7.9 over 10 for those who did the practice and 2.1 for those who did not, relating to a question on the calibration of a sensor. But also the global qualification of the exam, over 100 points, shows the effect of the experience: 77.1 was the mean among the students who participated in the active learning proposal and 59.3 that for those not involved in the experience. The cognitive dimension of the learning experience could be then qualified as successful, as students involved in the activity obtained better global marks than those who did not. This could be explained by the learning skills acquired during the practice.

These results move the staff to continue the experience in the next years, and to introduce it in the new design of the course, to meet the EHEA convergence process requirements.

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