Impact of Learning Experiences Using LEGO Mindstorms® in Engineering Courses

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Abstract— **It is well known by the educational community that active learning has a greater impact on the effectiveness of the learning process than other methods. It has long been recognized that the most effective learning techniques involve direct, purposeful learning experiences, such as hands-on or field experiences. In particular, computer-controlled models have been a useful aid in teaching programming, Artificial Intelligence and Robotics concepts. This paper describes our experience using LEGO Mindstorms® in three different scenarios: an elementary course on Programming, an advanced-level course on Artificial Intelligence and a third first-level course on Robotics. Our focus in those experiments is not on whether using LEGO kits is better than other methods to learn a programming language, AI algorithms or Robotics, but rather on introducing how this mixture of collaboration, competition and peer learning in a laboratory environment helps the students to increase their motivation and improve their professional skills such as problem solving, team work and leadership.**

Keywords: Active learning; LEGO Mindstorms; learning experiences, engineering courses, evaluation; assessment; surveys; empirical results; Java programming.

I. INTRODUCTION

After years of compelling research on the field, it is commonly agreed that the most effective learning methods involve direct, purposeful learning experiences, such as hands-on or field experiences. This fact is illustrated, for instance, by Dale's cone (Fig. 1), where passive learning would cover those activities that people can learn from, but not generally as effectively as active learning, which would include those activities that boost our learning experience.

Furthermore, active learning is even more required in technical studies (such as engineering), in which obviously concepts studied in class must be put into practice in different scenarios so that the students fully understand the fundamentals and also acquire the necessary competencies to apply them to solve real-world problems. Markets demand that professionals are mastered not only in a specific knowledge domain, but also in professional skills [2],[3], such as leadership, team work, autonomous and collaborative learning and management of increasing amount of information in short periods of time.

On the other hand, the European Higher Education Area (EHEA) [4] is investing a huge effort to foster the conversion of former ways of teaching into a modern type of learning. This new learning paradigm must be student-focused, holistic and comprehensive, helpful and encouraging, promoting autonomy and proactiveness, able to increase the student's motivation and disposition towards the course and thus improving the outcomes of the learning process. Apart from the competences specific to their curriculum, the integral vision of the learning experience is assumed to produce better qualified professionals. These professionals must have high added-value essential transversal (non-technical) competences that achieve the highest probability of success whether in current or further studies or their professional life. Team-work, communication skills and critical analysis are essential outcomes.

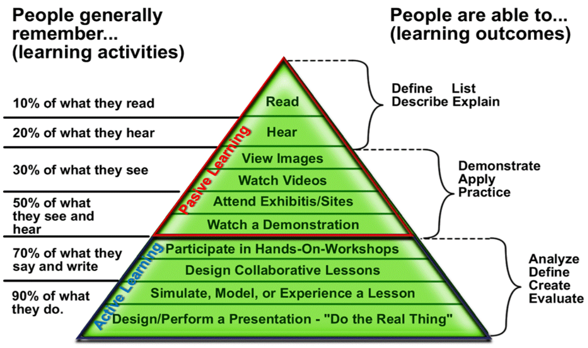

Fig. 1: Dale's cone [1] (released under a Creative Commons License)

This paper describes a series of experiments using LEGO Mindstorms® [5],[6] that have been carried out since 2005 in several scenarios involving a variety of student groups and course levels.

The purpose here is not to discuss the appropriateness or disadvantages of using those kits to teach technical topics, but rather to show how they increase motivation and improve professional skills. Activities that involve a mixture of real-world application of technical concepts, collaboration, competition and peer learning in a laboratory environment, achieve excellent outcomes in terms of students' motivation and development of transversal skills, and also improve their disposition towards hard tasks and their perception of the learning process quality. A critical analysis of how the methodology affects the learning experience is done, considering both subjective and objective results.

This work was partially supported by Learn3 (Plan Nacional de I+D+I, TIN2008-05163/TSI) and by Universidad Carlos III de Madrid (UC3M) on different calls for Experiences on Teaching Innovation.

We first review, in the background section, some previous experiences using LEGO kits in different environments. Then we place our work in context defining our goals with the introduction of Robotics in the different experiences. Then we discuss about our results and findings and how to use them in other context in future work. Finally we conclude about the usefulness of our experiences to improve motivation and develop professional skills.

II. BACKGROUND

Some studies [7] mention some of the conditions under which people learn properly, such as: what they learn is personally meaningful to them, what they learn is challenging and they accept the challenge, what they learn is appropriate for their developmental level, they can learn in their own way, have choices, and feel in control, they use what they already know as they construct new knowledge, they have opportunities for social interaction, and they receive helpful feedback. Projects using LEGO Mindstorms® have been proved as a good vehicle for implementing these concepts.

A. LEGO Mindstorms®

LEGO Mindstorms® [6] is a Robotics kit originally developed by MIT for building programmable robots. It combines standard LEGO blocks and LEGO Technic pieces (such as gears, axles and beams) [5] for its structure and a programmable brick and components (such as electric motors, sensors, etc.) for its control center (Fig. 2). The first generation of LEGO Mindstorms® was released in 1998 and was built around a brick known as the RCX. It contained an 8-bit 16MHz microcontroller with 32KB RAM. Programs written in one of several available programming languages are created on a computer and sent to the brick using an infrared (IR) interface. In addition to the IR port, there were 3 sensor input ports and 3 output ports (usable for motors and lamps) and an LCD that can display the battery level, the status of the input/output ports and which program is selected or running.

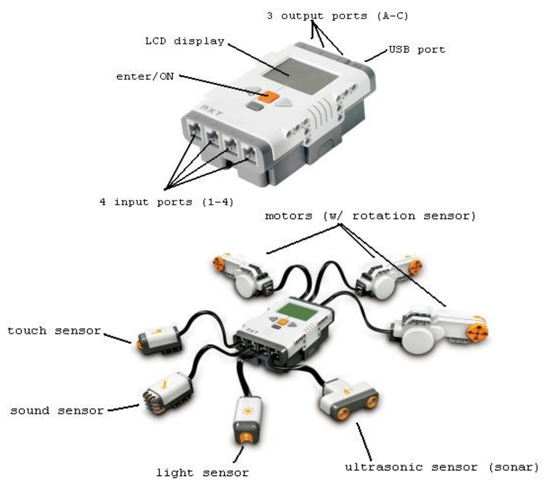

Fig. 2: Brick, sensors and actuators of the NXT kit

In July 2006, LEGO Mindstorms® NXT replaced the first-generation RCX. The new brick includes one main 32-bit 48MHz processor with 64KB RAM and 256KB Flash, and a second 8-bit processor for controlling an extended set of sensors and actuators. The brick also includes 4 sensor input and 3 actuator output ports, all of them with a digital I2C interface using a pseudo RJ12 connector. The IR interface is substituted by an USB and a Bluetooth port. The basic NXT kit consists of 519 Technic pieces, 3 servo motors, 4 sensors (ultrasonic, sound, touch, and light), 7 wires, a USB cable, a USB Bluetooth dongle, and the NXT brick. There also exist expansion kits that provide with more different building pieces and other types of sensors.

Initially the LEGO-supplied programming languages were RCX Code (assembly) and ROBOLAB (a graphical language). However, the enormous popularization of these kits led to the creation of new alternatives by the community, mainly as open source new firmware or virtual machines, supporting modern programming languages such as C/C++ and Java. For NXT, currently there exist over 30 alternatives including the Official Mindstorms SDK (Visual Basic, Visual C++, MindScript and LASM), the original ROBOLAB graphical language, leJOS (Java), NBC (assembly), NXC (C-like language), RobotC (C), GCC (GNU Compiler for C/C++, Fortran, Java, Ada, etc.), Ruby, Python, MATLAB, etc.

In general, the programming environment is simple enough to be learnt by the students easily. Thus, they can construct robots that perform complex tasks in a very short time. This combination of versatility and simplicity, together with its motivating potential, makes LEGO Mindstorms® a powerful help in a variety of learning scenarios.

B. Related work

Innovative teachers are continually looking for creative ideas, both to get their ideas across and to hold the interest of their students. With this purpose, LEGO have been widely used in different contexts with different objectives.

Fagin [8] and Schumacher [9] (2001) were among the first to introduce LEGO Mindstorms® in basic programming courses. Fagin used Ada language to teach basic control sentences (sequential, iteration or selection) and Schumacher used Java to teach fundamental computer programming concepts and introduce the concepts of autonomous vehicles, embedded computer systems and simulation. Barnes [10] (2002) also used Java and pointed out the usefulness of physical models to teach event-driven programming and the physical limitations of LEGO brick to achieve a good object oriented programming style. Wright and Gilder [11] (2003) explored the use of LEGO Mindstorms® in more advanced courses to design interdisciplinary senior projects to better prepare graduating students for their careers as engineers. His work covers robotics, algorithm state machine design, assembly programming language and compiler design concepts

All these previous work describe experiences with few students per course. Cliburn [12] (2006) reviews previous experiences and deploys a more ambitious one using LEGO Mindstorms® in 5 different courses during several years. As a conclusion of his work, Cliburn identifies three principles to consider to successfully designing these kinds of experiences. First, the project and the programming interface should support the objectives of the course and be relatively straight forward to learn. Second, the group size should be small to ensure that all students develop the required programming skills. The third principle is that students should be given time in class for building the robot. More recently, Jipping [13] introduced LEGO robots to teach Java bytecode (2007) and Talaga [14] (2009) to teach Artificial Intelligence (AI). LEGO was not only used to teach programming skills in different languages or AI techniques but also it has been used to develop professional skills [12] such as the experience proposed by McGoldrich [15] to improve peer learning or Barak's experience [7] to develop problem solving skills. All these studies reveal that using LEGO Mindstorms® in enriched collaborative learning environments has positive impact on student performance and motivation in most of the courses.

Comparing our work with previous work in this area, our main contribution is that our experience is not a punctual pilot one, but rather several courses in different context during a long period of time. We describe our experiences, like previous studies, but we also provide empirical data that support our conclusions gathered from different methods (direct observation, interviews, surveys, etc.). We also tackle the challenge set by previous work that suggests the need to collect data on how the student perceives this type of learning and research on how informal learning takes place in collaborative and competitive environments. Our findings are independent of age, cultural heritage and personal interest of the students.

III. Our Experience using LEGO Mindstorms®

Based on those previous experiences about the benefits of using LEGO to improve students' motivation, we decided to organize a workshop that consisted of a competition where the goal was to build robots that participated in different challenges. The competition was a team-league that took place in different sessions. Each of these sessions presented challenges of increasing difficulty covering different aspects of programming, robotics and AI algorithms. The duration of the session, the difficult of the challenge and the main issues involved (programming, robotics or AI) was based on the context of the course. Work was done in teams of 3-5 students.

This was in 2005 as part of an advanced level course on AI (experience I, 33 students). The experience was so successful that we decided to carry out a more ambitious project introducing LEGO kits as an optional activity for students in an elementary course in programming (experience II, 127 students), in 2006. Most of the data analyzed in this paper was collected in this second experience. We finally had the opportunity to carry out a third similar experience in an introductory course in Robotics (experience III, 24 students).

A. Experience I: AI Course

1) Context

Our first experience with LEGO kits started in 2005, when they were introduced in a course called Intelligence in Communication Networks (ICN) [16] (first semester, fifth year, Telecommunication Engineering). Students learn the fundamentals of AI, the impact of intelligent behaviours in information systems and the areas where these technologies may bring the most significant advances. The course is elective and involves around 45 hours/semester. Sessions with LEGO typically take place during 6 sessions within regular classes (9 hours in all). These activities have the same impact on the final grade as other assignments. The experience began in 2005-2006 and was so successful that it has been repeated annually until the present. We started with 7 RCX kits but we switched to NXT kits two years later, when 20 new kits were acquired.

2) Objectives

The introduction of LEGO kits in this course was partly motivated by a significant decrease in the number of students enrolled in the course during the academic year 2005-2006, when the average of 50 students enrolled per year abruptly decreased to 33. Despite other causes (such a general decrease in the number of students at university), we think that it was necessary to introduce new lab sessions in the laboratories that motivate students while practicing their newly acquired knowledge on AI applied to Robotics.

3) Challenges

Different AI techniques, among the topics explained during the course lectures, have to be applied to solve the different challenges, such as problem solving or kNN (k-Nearest Neighbour algorithm). This way students can develop and experiment these techniques applied in a real working system. Our experience shows that at the end of each session practically all teams were able to develop a robot that meets the specifications stated in the challenge.

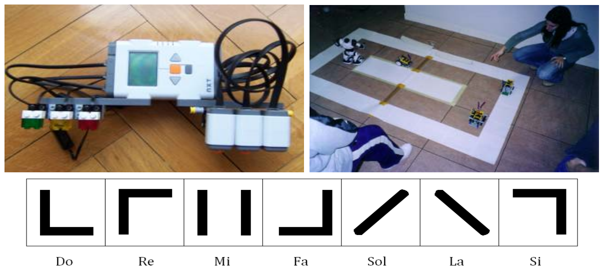

Fig. 3: Challenges in ICN course

In addition to an introductory session, three main challenges are posed to the students (Fig. 3):

- **Rock, paper, scissors**: Build a smart robot able to play that game. The purpose is to illustrate that most times an intelligent behaviour can be implemented with common-sense rules.
- **Escape from maze**: Build a robot able to run away from a maze. This task needs more advanced planning and solution search techniques.
- **Artificial vision:** Build a robot able to recognize and classify images. In this case, the aim is to implement a classifier using any of the studied techniques.

4) Methods and Results

The mixture of robotics, competition and collaboration reveals itself a powerful combination for learning AI. The students were highly motivated for this kind of lab sessions. The initial objective to increase the number of students enrolled in the course was reached as it can be seen in Fig. 4.

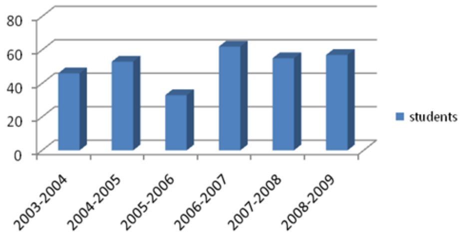

Fig. 4: Evolution of number of students enrolled in ICN course

As a collateral result, a significant increase in the number of Master's Thesis (Fig. 5) was achieved.

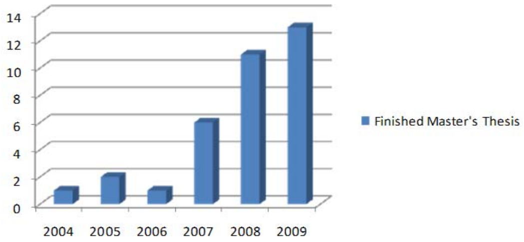

Fig. 5: Finished Master's Thesis supervised by the authors

This increase was mainly due to students who had been enrolled in ICN course, particularly in thesis about topics related with ICN contents, as shown in Fig. 6.

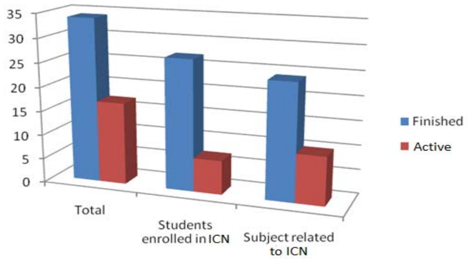

Fig. 6: Master's Thesis supervised by the authors related to ICN course

Annual teaching evaluation surveys show that the main reasons for choosing the course are the appealing syllabus and express recommendation from students of previous years. Although the relatively high passing rate could also influence the choice, we think that it doesn't constitute a key factor as this rate is similar to other subjects.

B. *Experience II: Programming Course*

1) Context

After this first successful experience in the first semester, LEGO kits were also introduced in four different introductory programming courses [17] taught in first year of different degrees, as an optional workshop at the beginning of the second semester, named Robot.IT![1] [18]. The experience began in 2006 with a pilot group of 127 students enrolled in these different degrees. The distribution of students by degree, in that academic year was the one shown in Fig. 7.

[1] IT stands for *Ingeniería Telemática*, our Department.

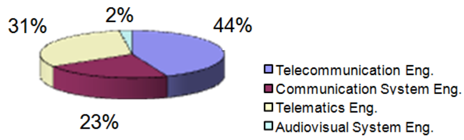

Fig. 7: Distribution of students by degree (2005-2006)

In this case, the workshop deployment has a significantly higher management cost than in the first experience, mainly due to the high number of participants. For this reason, the workshop is not organized on an annual basis but once every two years, giving the opportunity to join to students who enrolled in the subject that year and the year before.

2) Objectives

Programming courses during the second semester deal with algorithms and data structures (stacks, queues, trees, etc.). Students enrolled in these courses have previously received teaching during the first semester, on basic programming structures and object-oriented programming concepts. In general, results achieved by students during the first semester usually are not very good, and many students leave the course even before lectures start in the second semester. After the disappointing first semester results, it was necessary to influence student motivation to increase attendance of students enrolled in lectures and labs during the second semester.

The decision to introduce LEGO kits in those courses was largely motivated by the success achieved on our previous experience. Our main goal was to stretch the motivation gap between the first and second semester and to get student excited again about learning programming. To reach this goal we provide a different and enriched competitive and collaborative learning environment that fosters general interest in programming and illustrates the usefulness of programming in computer controlled physical models. Aside from the programming aspects, this environment also provides nice illustrations of two fundamental concepts that are often associated with Java: bytecode portability and the programmability of small devices as we mentioned above.

Our objective was not to improve student performance in courses, since the contents taught in the workshop had no direct relationship with those seen in class. For this reason the workshop was optional and has no impact in the final grade. The workshop takes place during 3 sessions outside regular classes with a total duration of 9 hours (3 hours per session).

During the workshop a teacher and a set of teaching assistants (typically two per session) help teams to resolve any doubt or technical problems. Teaching assistants are students chosen from among the course participants who have volunteered for this work. The teaching assistants have a short preparatory session with the teacher before the start of the workshop where they are trained in the tasks to be performed and the difficulties that arise in each session to be able to support their peers.

Finally, the large number of students involved in this second experience allows us to take some measures in order to evaluate the real impact of the workshop on student motivation and asses the methodology used during the experience. Issues related with the duration of each session, the number of sessions, the worst and the best aspects of the workshop, etc. were measured.

3) Challenges

Three challenges were posed to the students:

- **Robot Sumo Fight**: Build a robot that plays an all-against-all sumo tournament, pushing all the opponents out of the game area. This is a basic challenge to learn about light sensors and practice loops and conditionals.
- **Robot Recycler**: Build a robot able to find as many soft-drink cans as possible, pushing them out of the game field in one minute. This challenge involves several sensors and, optionally, advanced search strategies based on an ultrasonic (sonar) sensor.
- **Line Tracker**: Build a robot that can follow a path, a black line on a white surface, in the shortest time. This is a typical example of a non-trivial rule-based system.

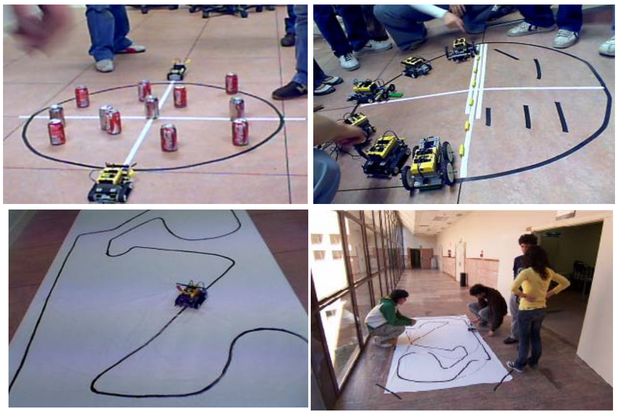

Fig. 8: Robot.IT! workshop

4) Methods and Results

A 40-question survey was designed to calibrate and improve some issues related to the **learning design** of the workshop, gather student opinion about the workshop **contents**, evaluate the impact in student motivation, evaluate **student's perception about his/her own learning**, evaluate the student's opinion about **using LEGO Mindstorms® in other courses**, evaluate their opinion about the **integration of workshop results in their grades**, and other questions (not related with this paper) about schedule, distribution of students by sex, how they knew about the workshop, opinion about the blog, etc. Survey has answered by 98 out of 127 participants and some conclusions can be drawn on each issue.

a) Results about the learning design of the workshop

- **Schedule**. Students agree with the session length (Question 19). 59% would keep as they are (3 hours), 37% increase in 1 or 2 hours. Only 4% of respondents would reduce the length of the sessions. Most people (82%) think that the difficulty of the challenges is adequate for the available time (Q20, Fig. 9). As each session was an independent challenge, we conclude that 3 hours is an appropriate time to address each of the challenges. In general, students are highly motivated, and despite the fact that the workshop involves about 9 hours (3 hours per challenge), takes place outside usual teaching hours and has no impact on the grades, surprisingly, most students (65%) would prefer to increase the number of sessions (Q18).

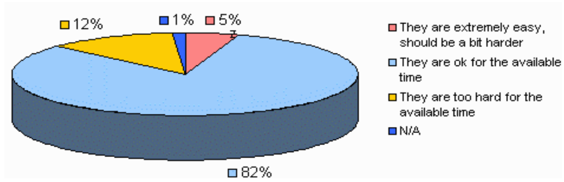

Fig 9: What do you think about difficulty of challenges? (Q20)

- **Groups**. When we asked students for the optimal group size (Q21), 59% would support increasing the group size to 4 people, 36% would keep the current suggested size (3) and only 5% which would reduce it. Despite students' opinion, our experience shows that the optimal size of groups is 3 persons because the pressure on the three members is just to keep everybody working. Increasing the pressure is likely to not complete the challenge and if the pressure decreases, there is a risk that some members do not work enough and the rest have time to absorb his work.
- **Teaching assistants**. Students highly value the presence of teaching assistants in class to support them during the session (Q23). 80% consider them a great help to overcome the challenges. Regarding whether they prefer to deal with the teaching assistants or teachers (Q24, Fig. 10), 61% prefer the teaching assistants because they are students and their relationship is closer. After the experience 30% of students would enrol as a teaching assistant in future editions.

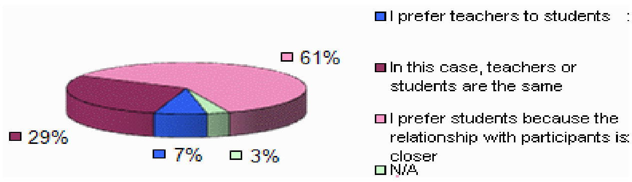

Fig.10. Do you prefer teacher or assistant support? (Q24)

- **Competition**. Most of the students (74%) consider the competition among groups highly motivating (Q30, Fig. 11). and 95% of the students agree in the importance of the competition factor in the workshop.

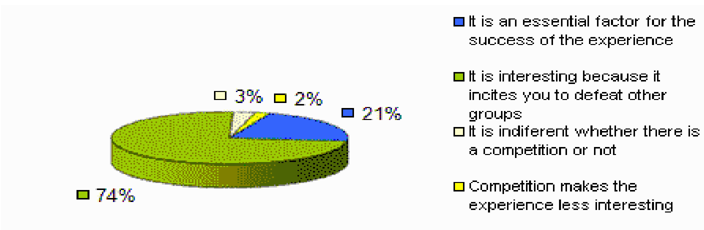

Fig.11. What do you think about the competition among groups? (Q30)

- **Preparatory work**. In order to analyze if preparatory work was necessary, we asked the students if previous lessons would have been interesting to improve the experience (Q16). Most students (56%) said it was not necessary since they could learn by themselves. 30% considered interesting to receive a previous lab class and 12% a previous lecture.

- **Students' preparatory work**. As previously mentioned, documentation for each challenge was provided at least a week in advance, and students were suggested to review it. When the students were asked if they prepared the sessions in advance (Q28, Fig. 12), most people (64%) answered negatively, and 60% said that they spent no time in preparing the sessions (Q29, Fig. 13). Despite the poor students' previous work, all the teams reach the challenges goal at the end of each session. We think that this lack of commitment from students is also because the workshop was conducted outside school hours and had no impact on their grades. When we asked what it would have happened if the workshop was a course for itself (Q31), students said they would have studied how to program the robot (62%), how to build the robot (5%), or the strategy to win the challenge (32%).

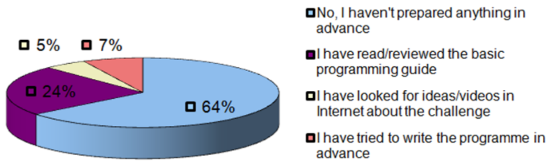

Fig. 12: Have you prepared the sessions in advance? (Q28)

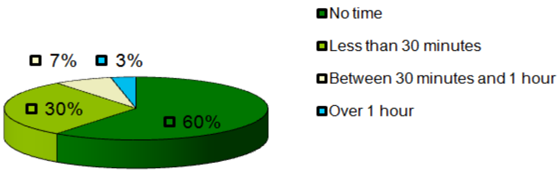

Fig. 13: How long have you prepared the session in advance? (Q29)

b) Results about content

- **Preferences**. When we asked participants which tasks they liked most (Q12), almost half of students (45%) responded that all of them in general, 26% preferred the work related to building the robot, 22% chose the hardware and software strategy design to solve the challenge, and only 7% preferred programming tasks. On the other hand, when they were asked for the most unpleasant tasks, half of the students (50%) answered that all of them in general, 25% dislike to write the control program, 11% to build the robot and 10% to design the strategy. We conclude that there is not a very marked preference for one kind of task with respect the others. 45-50% of the students do not manifest any preference. One of the most disliking tasks is programming in Java (25%) because it is one of most difficult task for them, as will be seen later.

- **Difficulties**. Tasks that are more difficult for students (Q14) are related to the integration and testing of the robot (43%) but these are not the ones they dislike. The next task by difficulty level would be programming (35%) and building the robot (17%). Although programming is considered by the students as one of the most difficult (35%) and disliking (25%) task, it is also considered the most important factor to win the challenge (53%) followed by good luck (30%) and building a mechanically good robot (13%).

- **Documentation**. Most of the students (55%) think that the documentation could be improved introducing more code examples (Q22). This issue has been solved in subsequent editions.

c) Impact of the workshop in student's motivation

- **Reasons to enrol**. When students were asked about why they took part in the activity (Q9), the two main reasons were to learn something about robotics (53%) and as a recreational activity (36%).

- **Subjects involved in workshop**. After the experience, students showed more interested in Robotics (Q37). 58% wanted to study more about this topic. Also they showed more interest in Java (Q38): 56% think that they liked programming more, and 44% kept the same opinion than before the workshop.

- **Overall opinion**. The general opinion about the experience was very good (Q10, Fig. 14) and 100% would recommend the experience to a friend (Q11). To calibrate their interest in the workshop, they were asked, as a kind of joke, what their response would have been if they would have had to pay to get better prizes (Q40). Surprisingly they would pay from the workshop. Most of the students (45%) would have participated for 3 €, 17% for 1€ and 23% for 5€.

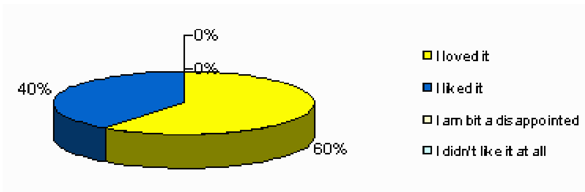

Fig.14: What is your opinion about the experience? (Q10)

d) Perception of the student about their own learning

- **Previous knowledge**. Only 5% has previous knowledge about LEGO kits (Q6), the rest (95%) had no knowledge before starting the activity. Regarding their self-perceived knowledge of Java (Q7), although all of them have a previous course in Java during first semester, in general (58%) their previous knowledge was not very high.

- **Knowledge about robotics**. 98% of the students say that they have increased their knowledge about Robotics. 58% also say that, as a result of the experience, they are more interested in Robotics than before (Q37).

- **Knowledge about Java**. Their perception of learning Java is lower than learning Robotics (Q35). 47% of the students answer that they have learnt about Java, but surprisingly, within this group, 32% felt that concepts learnt were not useful in their degree. In fact, we anticipated these results, because the content of the workshop was not directly related with the content of the programming course as it was mentioned before. Then students were asked about what they would change in the workshop so as to be able to learn more Java (Q36). Only 6% think you cannot learn Java using LEGO. The rest report that it could be useful to have a lecture explaining useful programming techniques (41%), others prefer to have more difficult challenges that need advanced techniques (24%), and finally others chose to have the same challenges, but forcing certain programming techniques (28%).

e) Integrating the workshop in their grades

When students were asked about their opinion if they have to grade the experience (Q31), 10% thought that it should be based on the ranking of the competition, 32% of the people report that the grades should be based on the quality of the robot and the degree of fulfilment of the challenge requirements, 45% thought that there should be a balance among those criteria and only a 18% report that the grades should be based on the evaluation of the robot by the teachers.

f) Using LEGO Mindstorms in other courses

After the workshop, most of the students (94%) report they would like to have some workshops like this in their studies (Q33). In this group, 29% would like to integrate this experience regardless of evaluation criteria, but 65% think that the evaluation criteria have to take into account not only the results of the competition but also the quality of the robot and the fulfilment of the challenges.

C. Experience III: Course on Robotics

1) Context

In the third experience, LEGO kits were specifically used in the context of a course on Robotics, included in the list of BEST summer courses. The Board of European Students of Technology (BEST) [19] is a non-profit organization that provides communication, co-operation and exchange possibilities for students all over Europe. BEST organizes different activities where students from member universities get the opportunity to increase their international experience, establish contacts, improve their English and have fun. Each course is attended by 20-30 engineering students. Participants attend lectures given by the university's teaching staff or by experts from companies. At the end of the course, students take an exam, designed to evaluate the participants' success. The title of the course was "My robot, my lovie and me" [20], took place in June 2009 and involved 24 participating students of different European countries, along with around 10 Spanish members of the organizing local committee.

2) Objectives

The decision to introduce LEGO kits in this context was motivated because it provides a different environment in which some concepts about engineering are learnt in an environment that promotes social interaction. As the course was specifically the LEGO workshop, we had the opportunity to assess the concepts taught during the sessions, without interaction of other elements such as lectures or other laboratory practice.

3) Challenges

Five challenges (Fig. 15) were posed to the students:

- **The chilling cable car**: Build a cable car able to pull itself along a string, as fast as possible.
- **The risky can recycler**: The same as the Robot Recycler challenge in experience II.
- **The impassible robot rumble**: The same as the Robot Sumo challenge in experience II.
- **The fearless cowboy**: Similar to the Line Tracker in experience II, with a higher difficulty level involving harder curves, tunnels, ramps and any sort of obstacles.
- **The grand death race**: Similar to the previous one but introducing crossovers, thus forcing robots to use more sensors to deal with this issue.

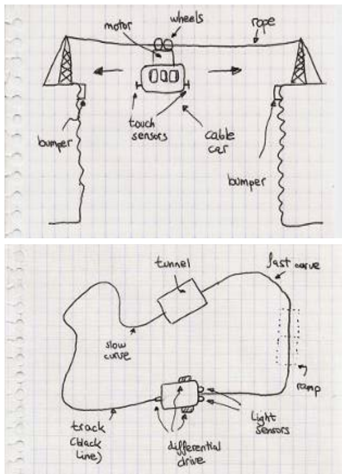

Fig. 15: "My robot, my lovie and me" challenges

4) Methods and Results

To calibrate the impact of the learning experience, an exam was carried out at the end of the course. The exam had 10 questions. Questions from 1 to 5 were about robot components and their behaviour in different situations. Questions from 6 to 10 were about programming the robot behaviour. In both cases with increasing difficulty of the first to the last question of each block. The results are shown in Fig. 16.

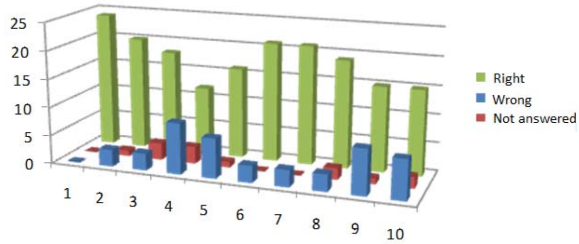

Fig. 16: Exam results in BEST Course

Student performance is high in both cases but noticeable a slight decrease in the number of questions answered correctly at the end of each block coinciding with the increase of difficulty in questions as shown in Fig. 16.

D. *Informal learning and workflow*

One of the most important results of these ongoing experiences developed over the last five years has been the observations gathered by the teachers and the teaching assistants who supervised the workshop. This information was directly collected by the authors during the sessions and through subsequent interviews to different participants. These observations provide valuable information on how informal learning takes place during the sessions.

One of the findings was that the workflow of the students was the same regardless of age, gender, country of origin or course level into which they were enrolled. It is also independent of the subject they were related to, whether the course was mandatory or voluntary, the result of the activity was or was not part of the final grade and even whether participants knew or didn't know each other before starting the workshop and groups formed spontaneously or as directed by the teacher. Typically the workflow was the following:

- **Understanding the goal and collecting information**. Students attend the teacher introduction and read information about the challenge (description, rules and hints). This information was available from one week before the session but students usually didn't review the material until they were directly challenged in the workshop as shown in Fig. 12 and Fig. 13.

- **Brainstorming and planning**. Then, they planned to outline the characteristics of the robot (large, small, light, heavy, number of sensors and actuators) and the general strategy.

- **Organization and division of roles**. Normally, and usually before finishing the previous stage, the students, trying to be efficient due to the pressure of the competition, begin to distribute the work among them, both explicitly (sometimes they reach an agreement on how to share out the work) or implicitly (sometimes it just happens naturally). It has been observed that there is a general tendency for women to handle more of the tasks associated with building the robot and men related to programming the brick, although this issue has to be further analyzed based on actual objective evidences.

- **Solving problems**. When first problems for each role appear, this is the typical sequence to solve them: 1) Ask team partners with other roles; 2) Review extra documentation (tutorials on building and programming robots using LEGO kits); 3) Ask teaching assistants or teacher(s); 4) Ask students in other teams with the same role.

  Some groups prefer to interact with other students rather than with the teacher, so they first ask the teaching assistants. However, the teacher usually gives a more effective technical help (especially in hard challenges), so some groups directly make this choice. In any case, we are not able to draw any conclusion because the choice can be simply based on availability (usually there is just one teacher and several teaching assistants).

  After the first round of questions, steps 3 and 4 changes the order and finally the sequence is 4 and then 3. This is because normally teaching assistants and teachers are in high demand and are slow to respond and therefore they finally prefer to ask students in other teams with the same role and similar tasks. In most cases, interacting with other teams is enough to solve the problem, and only in very specific cases the teacher support is essentially necessary, for example when the group is severely delayed with respect to others. In this phase, the main flow of information is among students in different teams with the same role, what we would call "meeting of experts".

  At this point, it is worth to notice that, although students provide information to other teams, there is no plagiarism because this help gives them clues to solve their problems, but does not provide them with the whole information that they have used because, after all, this is a competition.

- **Integration tasks**. When different roles advance in their task, they need greater interaction with teammates to integrate all efforts in the same direction because there are strategic decisions that heavily rely on work done by other members. In this stage of the work, there is an important flow of information among teammates who begin to learn about the tasks assigned to other members of their own team.

- **Testing**. Even though the students have tested their work in previous stages, during individual work, in this phase all the teammates work together to build the final result. In this stage the students learn a lot about the work developed by other teammates and all team members work together.

- **Improving performance** to be the better. At this stage, students inspect the robots developed by other teams in great detail and learn the best strategic decisions to integrate them in their own robots.

The mixture of collaborative and peer learning with a competitive environment have been proved to be a great tool to improve motivation and meaningful learning in our students.

When the students were asked about the methodology used during the session they are not always aware of the workflow followed, but the information collected by other sources shows that was the same in all experiments despite the different contexts in which they have occurred.

IV. Discussion

From the very beginning, we didn't think about these experiences as one-off events but instead as ongoing activities that we planned to repeat with a certain periodicity. In fact, once that the initial investment both in LEGO kits and accompanying material (such as sticky tape, ropes, game fields for the challenges, bridges or ramps for the track, etc.) and also in the preparation of teaching material (such as the descriptions of the challenges, the fundamentals of Robotics or AI techniques, tutorials, programming guides, hints, etc.), each new edition is less demanding and the effort for carrying it out is mainly limited to the time for arrangements (lab reservation, software installation), some cheap consumables and, obviously the teacher's attendance to the different sessions.

Specifically, experience I involving ICN course will be repeated on a yearly-basis during each academic year, at least while the current study plan is active. As shown in the result section, students' satisfaction is very high as proved by the annual course evaluation surveys and the increasing number of enrolled students, so it turns out to be a motivating factor.

Regarding experience II, Robot.IT! will continue to be a biannual activity. Here the requirements are considerably harder than in the first case, mainly because of organizational issues (for instance, sessions take place out of normal teaching hours, so we have to deal with the short availability of laboratories and constraints in student timetables) and also because they involve a high number of students.

The survey gives many details about technical issues to maximize success when carrying out activities involving LEGO kits. The results reveal that the optimum team size is three members; the session length of about 3 hours, the number of challenges depending on the available time, the difficult of the challenges proposed is adequate to the students' level of knowledge. Also the study shows that students prefer autonomous and peer learning and they prefer to be technically supported by other students than by the teachers, because the relationship with them is closer. Competition and social interaction are key issues that contribute to increase the student's motivation. Although the experience is fully satisfactory for students and increases their motivation to learn programming, the experience can be substantially improved by stretching the gap between the contents of the workshop and the content of programming courses. Our next steps will be oriented in that direction as we explain in the next section.

Finally, experience III is the least regular one, and whether there will be or not some new editions will depend on factors that are out of our direct control. However, developed materials and ideas can be easily reused in the other experiences.

To sum up, these experiences have illustrated that the participation in workshops as a form of active learning (Fig. 1) is highly motivating for students and contributes significantly to reinforce transversal skills (autonomous learning, problem solving and team work) learnt with this experience.

V. Future Work

There is still much room for improvement and there are still many new ideas to put into practice in the different scenarios.

From our point of view, in the case of experience I, the problem is that AI courses usually comprise a wide and compartmentalized syllabus covering many techniques and applications in different areas (though very briefly in some cases) that has to be taught (and learnt) in a few hours and by means of a limited short number of exercises. Interest in sessions using LEGO kits is not discussed, as students themselves think, but are in fact quite isolated. We find out that students sometimes have certain difficulties to reinforce those basic concepts or even learn them. In consequence, a major drawback of such didactic approach is that students focus on 3 or 4 topics from the entire course contents. Although deep learning of those topics is probably ensured, learning of the rest of the contents is also probably much more superficial. To overcome this limitation, the schedule has been yearly rearranged to solve some of these problems (mainly eliminating the less interesting topics for engineering students).

In another work, we proposed the application of peer review methodology [20] as a complement to the project-based learning approach in order to allow students to explore in depth other topics besides the one developed in their own projects. Preliminary results are promising, but these conclusions still have to be further studied in detail.

Regarding experience II, we want to strengthen the links among concepts introduced in the programming courses and the ones that students have to put into practice when they are programming their robots during the workshop. Our idea is to make a higher effort to improve the teaching process. First, we are interested in reviewing essential programming concepts such as different types of loops (for, while, do, until), the usage of conditionals (both isolated or inside a loop), the meaning of variables to represent a given state of an automaton, inclusion of arrays, etc. Then we would like to introduce advanced programming concepts, such as multitasking or event-oriented programming, which appear quite naturally during the challenges. In addition, we would like to give the participants and overview of advanced extra concepts related to engineering and Robotics (such as dynamic sensor calibration, basic driving techniques, degrees of liberty of a system, etc.) and/or AI techniques (such as search strategies for problem solving, rule systems, simple machine learning algorithms, etc.). We also will force the interchange of roles among team members in during each session to improve the learning of different skills.

In general, we have to catch the student attention to the workshop. Despite its attractiveness, the workshop is elective and competes against all other courses (compulsory, more important, failed from previous years...). Apart from the workshop contents themselves, there are probably many influential factors, for instance, their timetable or the academic calendar, which have to be considered globally as a whole.

Regarding experience III, no significant changes are planned to be introduced in eventual future editions of the course. However, the promotion of the course will be improved and lessons learnt from these experiences will be introduced.

In addition, a recurrent topic for us is how to foster the development of transverse abilities in students. Lacks in some basic competences are detected in students, such as idea communication, oral or written expression, critical analysis, self confidence, etc. Although this is more a continuous holistic process and the impact of these experiences is very hard to evaluate, we are interested in promoting those competences, so our plans include the incorporation of psychologists or educationists so as to research on this topic.

Finally one of the most important challenges for future editions of these courses is to integrate the conclusions drawn on how informal learning takes place during LEGO Mindstorms® workshop and introduce them in the lectures. To do this, we plan to propose enriched learning experiences, with weekly challenges to be solved by teams of three members. We will try to promote competition among teams and role interchange inside each team. We also provide material for autonomous learning and promote experts meeting among members of different teams with the same role to improve the learning, and integration meetings among members of the same team to fix relationship among concepts.

VI. CONCLUSIONS

In this paper, we have described our experience using LEGO Mindstorms® in different context in a period of five years. The originality of our study in relation to previous work is the length of the experience, the fact that it has been performed simultaneously in different contexts and the focus on the way in which informal learning takes place in these competitive and collaborative environments. We also provide a description of challenges, technical issues, parameters and references to implement this experience using LEGO. In addition, we provide the workflow description and list some lessons learnt about informal learning in order to enrich other learning environments not directly related with LEGO Robots.

We have shown the impact of using LEGO workshop in student motivation (Fig. 4). There was a 73% growth in the number of students enrolled in ICN (from 33 in 2005-2006 to an average of 57 students per class in subsequent years) as a result of introduce LEGO Mindstorms® in this course. 71% of the Master's Thesis supervised by the authors was directly related with ICN course (Fig. 5 and Fig. 6). All students surveyed (100%) would recommend a workshop like this and 94% would include similar experiences in other career courses. Measures about the benefits of competitive, collaborative and peer learning as they are perceived by the students have been taken. 74% of the students consider competition among groups a key issue to increase motivation (Fig. 11), 80% consider that teacher assistants are a great help to overcome the challenges proposed and 61% prefer asking other students rather than the teacher because their relationship is closer with them (Fig. 10).

Based on with the data collected during these experiences, we also calibrate some issues like the optimum group size, session length and number of challenges. We expect that the information provided by our experience can be useful to other groups interested in using LEGO Mindstorms® to promote active learning in their classes and maximize the success of their experiences.

ACKNOWLEDGMENTS

Thanks to our colleagues Raquel M. Crespo and Jesús Arias for their help in supporting and promoting these experiences. Thanks to Universidad Carlos III de Madrid for its support on the following calls for Experiences on Teaching Innovation: "Active Programming learning using low-cost robots as a motivating factor" (III call, 2005-2006), "And now, what? Development of professional skills and competences" (IV call, 2006-2007) and "Using new technologies in teaching practices to improve teacher-student interaction" (VI call, 2008-2009)

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