Hardware Project Development using Scrum in the Interactive Technologies Degree

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***Abstract*—Learning electronics in the fourth-wave industrial age requires an extra effort to motivate students. They often feel frustrated so they do not spend enough time to acquire in depth-knowledge. To enhance student´s motivation and engagement, instructional methods of teaching and learning are being tested in some Universities [1]. Among these methods, project based learning (PBL) has proven to be useful to overcome frustration and improve student engagement. This methodology is even more successful if it is implemented using an agile approach, like Scrum. This paper describes a new way to teach electronics based on the use of PBL and Scrum and presents results of its application regarding to the acquisition level of some competences.**

***Index Terms*—Project Based Learning, Scrum, Microcontrollers**

I. Introduction

The XXI Century is called the post-industrial epoch. There is no doubt that civilization is changing more quickly and deeply than it did in previous transitions. This presents a world of uncertainty where technology evolves faster than in previous eras. In the context of education, there is a big concern related to the way of teaching and learning in the new era. On one hand, some Universities advocate the establishment of a new paradigm based on a learner-centered approach [2]. On the other hand, most Universities in Europe are still organized following a teacher-centered approach. This situation is inherited from the industrial era where a new elite of theoretically oriented Universities were needed in order to overcome the challenges of the twentieth century. Nevertheless, today´s situation is different and we should provide our students with those skills that can contribute to cope with the continuous changes and to work in an uncertain environment, such as is addressed in [3].

Recent studies ([4], [5] and [6]) have highlighted a high dropout rate of engineering students in Europe, and more specifically in electrical and computer related degrees. Researchers point out that some of the causes of this problem are:

- The lack of preparation in basic concepts of mathematics and physics, which blocks student´s progression and finally causes a loss of confidence due to poor performance [7].
- Institutional factors such are the insufficient relation among subjects [5], syllabus too long, the lack of coordination among subjects in the same course and poor interaction with the faculty [9].
- The lack of intrinsic motivation which is strongly correlated to the interest that students have in their field of study and the expectation of achieving a successful professional future [10].
- Problems related to social integration of students in the academic environment [11].

In addition, a knowledge-based society requires that University degrees work on the development of transversal competences and skills that prepare students for the challenges of a constantly evolving professional future. On one hand, the curriculum must be designed in an integrated way; the subjects have to be interconnected and the development of transversal competences should be seen as a continuous and properly coordinated work [3]. On the other hand, the curriculum should:

- Provide a deep knowledge of technical fundamentals.
- Enable students to be able to create and operate new products, processes and systems [3].
- Convey the importance of technological development for the development of society.

In order to enhance intrinsic motivation and to overcome some of the problems cited previously, the teaching and learning methodology has to change. They should involve collaborative work and learning by doing. In this regard, an innovative degree called Interactive Technologies Degree (ITD) was designed in the Valencia Polytechnic University in 2017 [12]. The teaching methodology used is the project based learning (PBL) as a way to articulate a connection among all the subjects of the degree, and to integrate transversal competences in a natural way. An interdisciplinary project is included in each semester, each one is focused on a different technology such are Internet of Things (IoT) or Robotics and approached following the four phases of the CDIO methodology (Conceive, design, implement and operate) [3]. Seven multidisciplinary projects are developed in this degree, three of which are intensive in software development, videogames and AR/VR and four involve teaching electronics for the development of prototypes.

In this paper, we are going to focus on how electronic subjects have been involved in the projects developed in ITD. We are going to emphasize aspects related to the methodology used to lead the teamwork because this methodology allows us to integrate the acquisition of competences such as innovation, teamwork, planning and time management, project design and practical thinking. In section II, we present Scrum methodology applied to education, then we explain the four electronic projects that are being developed inside the curricula of the ITD. We go deep into the way that we work and evaluate transversal competences acquisition. Section IV shows the evolution of transversal competences acquisition, these have been measure using Azulay-Bernstein test, and a comparative between the competences acquired by students and those who have proffessionals. Last section presents conclusion and future work.

II. Scrum Applied to Hardware Development

Scrum is an agile approach applied to software projects since 2010 [13]. This is characterized by:

- Incremental development of the project through iterative processes.
- Flexibility in adapting the project features to the customer needs, thanks to the continuous involvement of the customer during the project design and implementation.
- Transparency among all processes which must be visible to those members involved in the project development.

Despite Scrum is usually applied in professional environments, it is currently being used in educational sectors because it presents some characteristics really suitable to provide a deep learning framework [18].

The applied Scrum methodology is presented in Fig. 1. The class is divided into groups of four to six students. This organization is performed using Azulay-Bernstein test [14], which is explained in section IV. This allows us to create balanced teams, where members with different personalities are present in each team. In addition to the team members, there are two important roles involved in the project:

- The product owner, who is responsible to represent the needs of the customer and the stakeholders.
- The scrum master, who is the facilitator of the work. In the educative environment the scrum master has to provide all the resources that the team needs to develop the project.

The project starts with the kickoff meeting. Here, the product owner, the scrum master and the whole team meet all together in order to present the problem that the project has to solve. After this meeting, the phase of conceiving the idea starts. This phase is acompanied by an intense work of technological surveillance, where students research about the state of the art, and some creativity sessions where teachers try to awaken creativity and interest of their students. The outcome of this phase is the Product Backlog, a list of product features described as user stories.

After the conception phase, the team begins to work in the design and implementation phases. This iterative process allows us to achieve a minimum viable product (MVP) at the end of each sprint. It initiates with a Sprint Planning where the team decides which features are going to be implemented in this sprint. It depends on the progress of the course and the availability of the team. In order to help students, teachers offer a detailed course plan, so that they know which contents are going to be delivered in each course week. The outcome of this Sprint Planning is the Sprint Backlog, where students describe not only the features to work on, but also which member is responsible for each one. Thanks to this, teachers are aware of the work that each student is developing inside the team.

During the sprint, students meet regularly (these meetings are called daily sprints) reporting their achievements and failures. These reports are used by teachers to follow up the team work.

The product owner, the scrum master and the team participate in the Sprint Review at the end of each sprint. This event provides an opportunity to revise the development of the product and discuss about the features presented. The team has to be open to change some aspects of the product if the product owner considers it necessary. In this way, students are receiving feedback about their work, promoting a culture of continuous improvement.

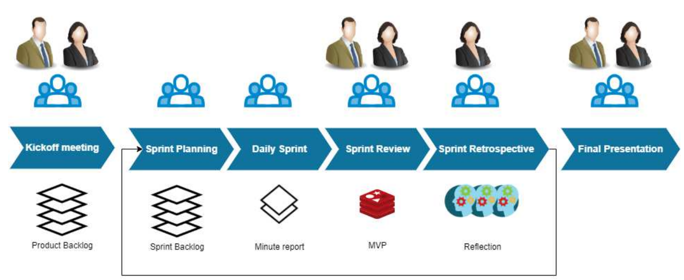

Fig. 1. Scrum process

Last event of each sprint is the Sprint Retrospective. This is a meeting where the scrum master and the team reflect about the work done in the sprint. Not only are technical aspects of the MVP inspected in this meeting, but also organizational aspects related to teamwork are addressed. In this way, students are obliged to reflect about how they communicate with each other, how they plan the tasks of the sprint and how they manage their time. In order to obtain indicators related to the work that each student performs inside the team, teachers have created a questionnaire that is filled by each student at the end of the sprint. The questions of this form are focused on how they perceive the work done by their counterparts.

At the end of the semester, teams present their products in public. Teachers invite firms and other stakeholders to attend to this final presentation where products are exposed. This is a perfect way to enhance interaction among University and firms and to bring University closer to society.

III. Hardware development projects in Interactive Technologies degree

Electronics is a field that adapts easily to a learner-centered paradigm. It is easy to expose a problem that can be solved using some electronic devices. Students are acquainted with electronics devices because they use them daily. On one hand, the implementation of an electronic project is economically affordable; on the other hand, the complete system is usually compose of several subsystems that allows introducing different disciplines.

TABLE I
Description of the Electronic Projects

Semester	Project	Scrum	Subjects
1	Monitoring physical parameters	Fundamentals	Basic Electronics Programming
3	Internet of Things	Development	Programming App Microprocessors
5	Air pollution monitoring	Improving design process	GIS Calculus
6	Robotics	Integration Tesing	IA Energy Harvesting Control

There are four electronic projects in ITD. Table I presents a brief description of these projects. The first semester, students are enrolled in a subject called “Development of an electronic project following Conceive, Design, Implement and Operate methodology” [3]. This subject is focused on explaining how the process of creating an electronic product should be. In order to internalize this process, a small project is conducted from its conception to its operation phase. The project is based on monitoring some physical parameters (temperature, humidity, atmospheric pressure...) using basic sensors that allows us to introduce physical aspects and to work with simple electronic circuits. A basic microcontroller (Sparkfun ESP8266) is used to monitor these parameters. It is programmed using C++ language. This first project involves subjects such as “Programming” and “Basic Electronics”.

The project is the same for all groups and it is guided by teachers, as students are in their first semester and a big degree of uncertainty could have adverse consequences. The development of the project includes defining the functional requirements, design condition circuits for sensors, schematic design, and implementation of a basic printed circuit board, testing and prototyping.

The learning outcomes of this project are focused on achieving that students be able to manage an electronic product from a system-level perspective. That means that they are not able to create software drivers to manage this system but they can use drivers already done and are able to configure them in order to achieve some features. These outcomes evolve in the other projects in order to specialize more deeply.

Furthermore, this is the first experience related to teamwork in University to enhance intrinsic motivation and to avoid student’s dropout. To achieve this, teachers take both product owner and scrum master roles. As product owner, they incorporate business experience into the class offering lectures related to the business models and the importance of entrepreneurial culture. As scrum master, they act as mentors and facilitators, who guiding students during adaptation to University. Moreover, students learn how to:

- Divide into tasks each one of the user stories planned to implement in the sprint.
- Measure the workload and estimate the task effort through a burndown diagram.
- Coordinate the work and manage conflicts.

These aspects are supervised by the scrum master who revises the team board every two weeks and uses the sprint retrospective to redirect the team work to make it more efficient.

This project continues in the second semester with the implementation of a web application whose goal is to monitorize all the parameters acquired.

In the second year of the degree, during the first semester, students are faced with the most technologically complex project, in terms of the number of technologies of different nature that it involves. This is the Internet of Things (IoT) project. Here the students choose for the first time in their studies which problem they want to solve. They are given total freedom and only one premise has to be fulfilled: interactivity between the user (using Android App) and the gadget.

To achieve this interactivity students are guided through incremental sprints with the following knowledge:

- Sensors, actuators and microprocessors of the ESP32 family.
- Raspberry Pi and Java.
- Communication algorithms (Bluetooth, UDP, MQTT).
- Applied Android and Google Assistant.

The teacher’s mission is to detect internal imbalances between the team components and ensure that the projects comply with the premise, as the students work with scrum autonomously (under the teacher’s watchful eye). In parallel with this project, students are enrolled in two subjects that give support to the project, “Microprocessors and Signal Conditioning” and “Mobile application implementation”.

External companies participate in this project by supplying their IoT gadgets in order to discover new applications born from the creativity of the young students and a presentation event is held where companies interested in the products developed are invited. With these contacts, University-business feedback is fostered, the employability of the students is favoured and entrepreneurship is stimulated.

The fifth semester’s project (Information, awareness and interaction through air pollution maps generated via mobile crowdsensing) focuses on the introduction of new technologies and on strengthening the core skills. Students develop a product consisting of a small, wearable Bluetooth air pollution sensor, a web page and a mobile app. Data are sent from the sensor to the mobile phone, and from here to a remote or cloud server where pollutions maps are generated. Citizens can access real free air pollution maps for their town, exposing local anomalies not shown in other commercial applications based on large-area interpolated data. Users carrying wearable sensors enjoy additional and gamified functionalities.

Students get acquainted with Bluetooth beacons, electrochemical gas sensors and their signal conditioning, crowdsensing solutions, 3D-printing technology (for the wearable sensor case), 2D data interpolation and representation and database design. In parallel, students take subjects on "Geographic Information System (GIS)" and "Calculus", which provide the basis of 2D data interpolation and representation.

In this project, students are demanded higher product quality and a deeper understanding and assimilation of agile project methodologies. Regarding quality, user stories that show less than flawless performance are not accepted. Good practices (such as code commenting and testing or using a version control system) are demanded and evaluated. Regarding agile methodologies, teams must choose a scrum master among its members. They must provide daily scrum logs and Kanban boards as evidence, and are subject to sprint retrospective meetings to analyse the team dynamics. The focus is set on their ability to manage conflicts and on their commitment to the project success.

In the sixth semester a project focused on robotics is implemented. The application of the project is free but there are some features that all projects have to match. These are:

- The robot has to be able to navigate autonomously.
- The robot has to capture and process images.
- The robot has to integrate some application related to artificial intelligence.
- The robot has to be controlled using a web application.

Students tend to implement projects related to security tasks, exploration in risky environments, agriculture tasks, health care, surveillance etc. The syllabus of the course is focused on contents related to python programming, teaching Robot Operative System (ROS2), OpenCV and neural networks. In parallel, students are taking classes on "Artificial intelligence", "Energy harvesting" and "Electronic control".

In this project, students are very autonomous, they know how to apply Scrum, plan the sprints, divide user stories into tasks and measure the task effort. The handicap of the work team is how to deal with conflicts and how to manage time. Teachers' work is less demanding than in previous projects and it is more focused on mentoring in contents than in the process of the team work.

IV. Results

This section presents results of two different analysis that have been carried out with the students enrolled in the first graduating class of the ITD.

- Analysis of the students competences development.
- Comparison with the competences that present professionals of the technological sector.

A total of 15 students have participated in this study, 2 women and 13 men. All of them were under 25 year old.

A. Analysis of the competences development of the students

Students of the first graduating class in ITD were classified using Azulay-Bernstein test when they were in first course and again in the fourth course. Emotional-DNA test (eDNA) was developed by Elías Azulay in 2014 following the theory of the transactional analysis proposed by he psychiatrist Eric Berne in 1972 [17] and its neurobiological correlation with respect to the neuromodulatory systems enunciated by Eric Kandel, Nobel Prize in Medicine and Physiology 2000 for the study of the neurotransmitters that govern behavior and learnability ([15] and [16]). This theory replicates the synaptic model of people through the eDNA algorithm and makes individual mental processes and human interaction explanaible, understandable and shapeable by means of looking inside people and the way that they communicate with each other, in addition to delving into each person's ability to modulate their synaptic response in their behavior and learning. One consideration must be taken into account, values greater than 90 points indicate loadings that are not positive. This saturation limits the ability to combine skills, harming the breadth of skills to be developed.

This test is being used in selection processes in businesses in order to minimize adaptation risks and in the educative sector for testing student's competences. The test is composed of 59 questions about how people reacts in different situations. This test offers as outcome a numeric pattern that establishes the emotional behavior of a person. This pattern contains seven registers, which are:

- Objectivity and reflection level (Ob) related to the serotonergic system. Order, good sense and responsibility are found here.
- Generosity and social and affective availability (Pr) related to the oxytonergic system. Here are cooperation, participation and teamwork.
- Analytical skills (Ad) related to the cholinergic system. Here are decision making, concentration and specialization.
- Spontaneity, imagination and creativity (Nt) related to the dopaminergic system. Risk, curiosity and creativity meet here.
- Attention and learnability (Sm) related to the neurotransmitter GABA. Here you find submission, passivity and enchantment. This register has an inverse scale. The higher the score, the lower the active listening and selective attention.
- Aggressiveness and possessive tendency (Rb) related to the adrenalinergic system. Here is found the most primitive subjective behavior.

- Influential capacity, foresight and cunning (Mn) related to the noradrenalinegic system. Here are the adaptive capacity, the intuition and the acceptance of challenges.

Our behavior is the result of the oscillations of these systems and their combinations. Therefore, various algorithms are activated to determine the level of acquisition of skills. In this study, the competences selected have been those which are developing in the projects. These are innovation and creativity, design and project, teamwork and planning, application of practical thinking and time management.

Data were processed individually to obtain the evolution of each student, and in a group, to see the improvement of the group between the first and the fourth year of studies.

The evolution of the group registers after four years studying ITD was presented in 2021.

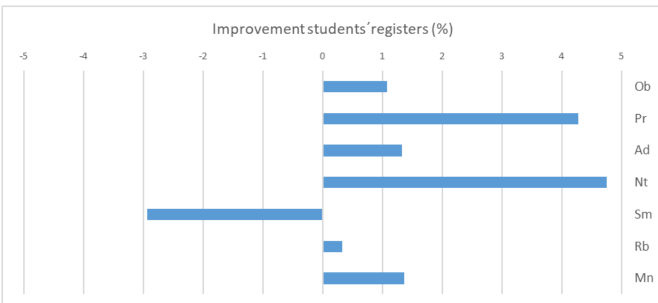

Fig. 2. Evolution of registers in percentage

Fig. 2 presents the evolution of the seven registers as the difference between registers measured the fourth year minus those of the first year. It shows that all registers have increased except the "Sm" register, which indicates that submission and passivity have been reduced to enter specialization, active listening and selective attention. Therefore, a reduction would indicate a determined learning with greater awareness.

Regarding to the essential records of behavior, we can ensure that people's neuromodulatory systems have been worked on to achieve an increase in their resources. Results presents an average increase of 3.31%, but the most relevant data are given in an increase of 5.86% (Pr) in the disposition in teamwork, 7.20% in the application of creativity (Nt) and 4.18% in relation to the focus of specialization (Sm). For this reason, the evolutionary process of the students of this discipline is enhanced in these capacities.

Fig. 3 presents the evolution (in percentage) of the selected competences, comparing the level that students have when they entered to the University with the one at the end of the fourth year of study. The most enhanced competences are those related to cooperation, participation and the provision of help in teamwork. In addition, the security provided by the acquired knowledge offers substantial improvements in innovation, creativity and entrepreneurial initiative.

Fig. 4 represents the percentage data of the competence level variation from the fourth year regarding to the first. Increments are between 1.2% and 3.5%.

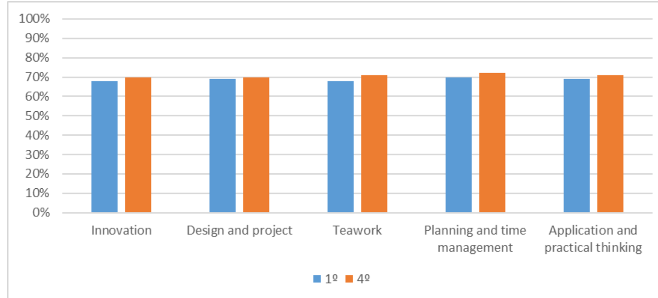

Fig. 3. Evolution of the Competences

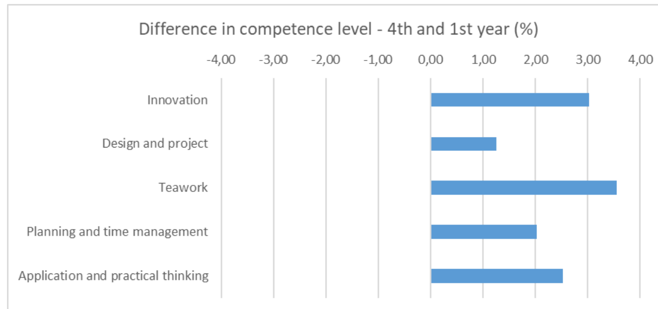

Fig. 4. Difference between competence level in the fourth year minus competence level in the first year, measured as percentage

After analysing these results, we can concude that personal progression is guaranteed, as it is based on the subjective parameters of each one. Likewise, through specific actions, other competences could be strengthened.

Let us not forget that the selection of the studies to be carried out by the students is often representative of their natural abilities in which they stand out the most. Therefore, these measurements confirm that when you learn, you really learn to combine, balance and dose the elements of the neuromodulatory model that each one possesses. Being, the passage through the university, a way to guarantee personal and collective evolution.

B. Comparative measurement between graduate students and professional managers

In order to estimate the progression from student to a seasoned professinal, we have made a comparison between the results obtained in students and those measurements made to expert professional managers.

The sample is made up of 78 managers (partners) belonging to multinational corporations with strong involvement in the technology sector. This sample is not segmented by gender. These are executives between 30 and 55 years of age residing in Spain but with international projects.

The graph of the Fig. 5 presents the comparison between ITD competences level and professionals. It shows that students have already some hard work to do, but they are on their way.

In order to have a clear idea of the magnitude of the improvement, we compare in Fig. 6 the score for first-year

Fig. 5. Comparison (in percentage) of the acquisition of the students competences with professionals

students and professionals, and the score for fourth-year students and professionals, as a percentage of improvement. This graph shows clearly than differences have been reduced by half.

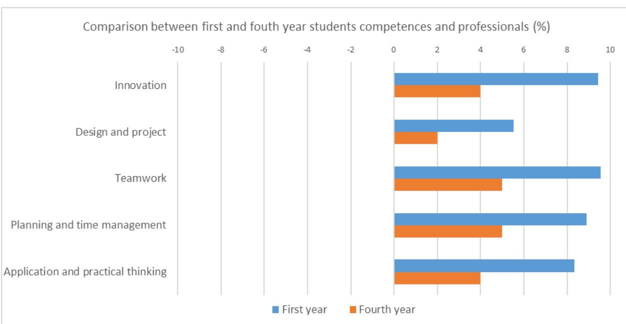

Fig. 6. Comparison between first year and fourth year students competences and professional competences shown as a percentage

V. Conclusion

This work has presented an academic methodology that emulates the reality experienced in companies, especially in the technology sector. The implementation of PBL through the CDIO and SCRUM methodologies make this degree an excellent training ground for students to acquire the competences that companies demand for a successful integration into the labour market throughout the four years of the degree.

The adopted methodology encourages students to be active learners, to reflect about their work and to collaborate with other students. Furthermore, it stimulates innovation and creativity, this can be demonstrated through the results obtained using eDNA test.

The curriculum presented in the ITD allows to interconnect subjects and introduces transversal competences naturally. In this way, students are developing skills needed in the knowledge economy, contributing to increase their competitiveness.

As future work, it is intended to carry out a similar study with students of the Degree in Telecommunication, Sound and Image Systems (SISTD), which uses a traditional study methodology but also introduces the realization of a project in fourth year. The level of skills acquired by both groups (the ITD group and the SISTD group) will be compared to analyze the differences.

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