HOW TO MEASURE STUDENTS' PERFORMANCE IN PBL?

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Abstract

In this paper, we present an analysis of metrics for teamwork efficiency in University degrees, by considering Project Based Learning as a teaching methodology. We defined indicators to evaluate the ability to prioritize tasks, the group communication and the produced value. Such parameters were designed to provide objective information about teamwork efficiency. To test the effectiveness of the proposed indicators, an experiment based on a classic team-building game was performed in the context of the Interactive Technologies Degree at Universitat Politècnica de València. Students were divided into two groups (one from the first course and another from the fourth course) and were asked to solve a problem in a limited amount of time. Our hypothesis was that the group corresponding to the fourth course would achieve higher teamwork efficiency because of their experience with the Project Based Learning methodology. After measuring the proposed indicators and other state-of-the-art parameters, we assessed the evolution and improvement of teamwork efficiency by comparing the results of both sets of metrics. Finally, we concluded that the presented metrics can be useful for teamwork efficiency evaluation, but also for students to manage their work.

Keywords: PBL, Scrum, Teamwork.

1 INTRODUCTION

In 2004, the National Academy of Engineering (NAE) celebrated a summit to discuss what engineering education should be like, to adequately prepare students for effective engagement in the engineering profession in the 21st century. This summit brought together people from universities and the private sector and was a fruitful forum that provided some recommendations to improve higher engineering education [1]. One of these recommendations is to "introduce the essence of engineering early." In this way, not only do students stay highly motivated, but also they learn some skills required for the practice of engineering in the 21st century.

Following this framework, a new technological degree was designed at Valencia Polytechnic University (UPV) in 2017 [2]. This degree proposed project-based learning (PBL) as the backbone of the curricula. It includes seven technological projects (one in each semester) where students must implement a minimum viable product (MVP) following the Conceive-Design-Implement and Operate (CDIO) methodology [3]. These projects are managed using Scrum principles [4], so team organization is essential to achieve a successful outcome.

Given the complexity of the projects that engineers will cope with, students must learn how to manage teamwork and measure performance. Researchers from several fields have studied what makes teams work effectively and how to measure teamwork performance. A bibliographic review can be found in [5], where the evolution of team effectiveness since the mid-1960s is presented. This paper addresses how team performance has been measured in the past and how it is changing by introducing affective reactions and viability outcomes.

In an educational environment, measuring teamwork performance becomes an arduous, time-consuming task. It must be frequently done to provide feedback and lead to learning goals. It requires perfect coordination among lectures to avoid misleading information and to become the learning experience more grateful. Intending to make this task more manageable and less time-consuming, this paper's authors have worked on an innovative educative project (PIME). One of the outcomes of this PIME is to enumerate a list of parameters that can be used to measure teamwork performance. To achieve this, teachers had to work collaboratively to establish how to evaluate these parameters inside the projects developed in each semester.

This paper presents the results of this research within the context of the Interactive Technology Degree (ITD), which is presented in section 2. It began with a bibliographic analysis, which is shown in section 3.1. From this, we obtained some metrics and discussed how they can be calculated. This discussion is

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presented in section 3.2. To provide results, we performed an activity where students from the first and fourth courses implemented a product in a session (see sections 3.3 and 4). Finally, section 5 concludes the paper by summarising this work´s contribution.

2 CONTEXT: INTERACTIVE TECHNOLOGY DEGREE

UPV has developed a new degree, called the Interactive Technology Degree (ITD), whose mission is to train professionals who can face the challenges of the 21st century. Students will be capable of creating products that interact with the five senses of the human being and their environment, to cover the needs of the sixth wave of innovation [6]. The main innovations introduced by this new degree can be summarized in the following points:

1 Project-based learning is used in all semesters of the degree without renouncing to delve into the theoretical contents promoting self-learning.

2 Creativity and innovation are encouraged, working on them from the first course and rewarding projects that present differential aspects.

3 The structure of the degree has been designed so that it breaks with the rigidity of the traditional study plans, creating project subjects of 12 credits that will be adapted to the technological changes of the moment.

4 Professional and business relationships are encouraged. It is a degree connected to the business world.

5 New technologies of the information society and communications are utilized: the subjects are designed using collaborative tools that the university facilitates.

6 The transversal competencies are perfectly intricate in the plan of studies. They are not worked on in isolation but are wholly integrated into the project subjects of each semester. In this way, it responds to the demands of the business world.

Table 1 explains the seven multidisciplinary projects that are developed in this degree, three of which are intensive in software development (web development, videogames and virtual and augmented reality) and four involve teaching electronics for the development of prototypes [7].

Table 1. Projects developed in ITD

Semester. Project	*Description*
1. Monitoring environmental parameters	Implementation of a monitoring system using basic sensors and a microcontroller
2. Web Development	Implementation of a web app to visualize parameters obtained in semester 1
3. Internet of Things	Implementation of a mobile app that allows us to interact with the environment
4. Videogame	Implementation of a videogame using Unity
5. Air pollution monitoring	Development of a small, wearable Bluetooth air pollution sensor, a web page and a mobile app.
6. Robotics	Programming a robot, controlled via web, and able to navigate autonomously, capture images and integrate an artificial intelligence application.
7. Virtual and augmented reality	Implementation of an advanced 2D/3D interactive environments application in real-time.

These projects are managed using Scrum [4]. Since 2010, Scrum has been an agile approach applied to software projects. It is characterized by (1) incremental development of the project through iterative processes; (2) flexibility in adapting the project features to customer needs due to the customer's continuous involvement in the project design and implementation; (3) transparency among all processes which must be visible to those members involved in the project development. Despite Scrum typically being used in professional settings, it is now being utilized in educational sectors due to its characteristics making it an ideal framework for deep learning [8].

The applied Scrum methodology is presented in Figure 1. The class is divided into groups of four to six students. In addition to the team members, there are two critical roles involved in the project:

- The product owner represents the needs of the customer and the stakeholders.
- The scrum master is the facilitator of the work.

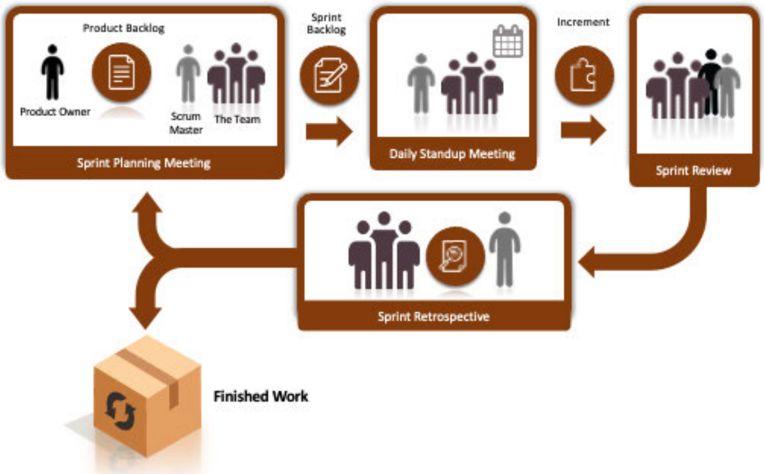

Figure 1 Scrum applied in ITD

At the first meeting, the product owner, scrum master, and entire team come together to discuss the problem the project is meant to solve. Following this, the idea conception phase begins. During this phase, students research the state-of-the-art, and teachers lead creativity sessions. The result of this stage is the Product Backlog, a compilation of product features expressed as user stories.

After the conception phase, the team works in the design and implementation phases. These phases are divided into sprints of two or three weeks. Each sprint initiates with the Sprint Planning, where the team decides which features will be implemented. It depends on the course's progress and the team's availability. In order to help students, teachers offer a detailed course plan so that they know which contents will be delivered in each course week. The outcome of this Sprint Planning is the Sprint Backlog, performed on a **collaborative board**, where students describe the features to work on and 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 hold daily sprints, where they report their successes and failures. This allows teachers to monitor the progress of the team through the review of the **daily minute reports**. Furthermore, a **sprint burndown chart** is used to track the progress of a sprint by displaying the amount of work planned for each day and the amount of work completed. It provides a visual representation of the difference between the estimated and actual results.

At the end of each sprint, the product owner, scrum master, and team come together for the Sprint Review. This event is a chance to assess the product's progress and discuss the features presented. The team must be willing to alter certain aspects of the product if the product owner considers it necessary. Afterwards, the team and scrum master come together for the Sprint Retrospective. This meeting offers an opportunity to review the MVP technical aspects as well as the organizational dynamics of the team. It is a chance to improve team cognition. Teachers have created a **survey** to be completed at the end of the sprint to gain insight into each student's work within the team.

At the conclusion of the semester, teams showcase their products in a public presentation. Invitations are extended to firms and other stakeholders to attend this final event, providing an opportunity to foster collaboration between the university and the business world and bring the university closer to the community.

3 METHODOLOGY

The methodology followed by this research consists of three phases:

1. Literature review to establish the state-of-the-art.
2. Discussion about metrics to be used to measure teamwork performance.
3. Activity to compare teamwork performance between first year and fourth-year students.

3.1 Literature review

The literature review follows protocols for searching, classifying, and analyzing the selected papers. Initially, we chose the most relevant journals in the field of education to have a general picture of how PBL is developed in technical degrees. Regarding this, the work performed by [9] was helpful because it collected more than 40 experiences from 2001 to 2017, classifying them depending on the number of cites and the journal impact factor. Furthermore, we developed an extensive search in journals related to economics, management, and social behavior. From this review, we got 50 papers that were classified in terms of their main contributions to:

- Team formation.
- Metrics to evaluate teamwork performance.
- The importance of role-based team organization.
- How to solve conflicts in teamwork management.
- Methodologies to manage teamwork.

A second revision of these works allows us to remove duplicities and focus on those papers that introduced parameters that influence teamwork effectiveness. In this way, we reduce the number of works to 16. These papers were carefully studied to produce table 2, where their main contributions and parameters that influence teamwork effectiveness are presented.

Table 2. Summary of literature review

Article	*Contribution*	*Parameters that influence teamwork effectiveness*
[10]	Study of different kinds of teams	Autonomy degree; dynamics of collaboration degree; openness to diversity; communication; cohesiveness; interdependence; conflict resolution; affectivity
[11]	Practical aspects related to group formation and management	Conflict management
[12]	Causes and effects of affective climate in teams and how leaders can cope with them	Affect
[13]	Understanding of team cognition is critical to improve team performance	Team members share mental models. cross-training (members receive training, not only for its own position, but also for other´s position)
[14]	Teamwork skills must be taught	Cohesiveness, reflect on how the team works
[15]	Guidelines to carry out a satisfactory teamwork experience	Role's distribution; planning; clear the goal
[16]	Guidance from the instructor on effective teamwork had a significant effect	Level of instructor guidance; ability to sanction uncooperative team members
[17]	Development of teamwork related skills using PBL	Planning; task division; dynamics of cooperation; communication
[18]	Teamwork effectiveness review	Team cognition; affect; cohesiveness; interdependence
[19]	Applying Scrum to PBL	Internal communication; autonomy degree
[20]	Applying Scrum in professional environment	Autonomy degree; clear the goal; internal communication; reflect on how the team works
[21]	Evaluating teamwork skills in educational environment	Conflict management; internal and external communication; dynamics of collaboration; leadership
[22]	Positive and negative aspects of applying PBL	Level of instructor guidance; leadership
[23]	Dynamics of virtual students' teams	Task division; dynamics of collaboration
[24]	Cooperative learning improves students learning outcomes	Planning; academic background; cohesiveness
[25]	Team performance in professional environments	Leadership: reflect on how the team works; dynamics of collaboration; internal communication

From the previous analysis, we got a list of characteristics that allow teams to become highly efficient. These parameters are:

- Teams must be autonomous: self-organizing teams can take greater ownership over the product and generally manage their responsibility with more outstanding prowess [4].
- They must establish collaboration dynamics: the work must be divided into tasks, but team members need to collaborate to review other members' tasks or help when a counterpart is stuck with his task.
- Internal communication is crucial to achieving good team performance. All members must be aware of what the rest of the team is doing.
- Conflict management: interpersonal problems arise sooner or later, so teams must be equipped with strategies for dealing with conflicts.
- Role distribution allows teams to clarify responsibilities and contributes to improving team creativity [25].
- Planning and task division are essential to cope with complex projects. Teams must spend time planning before getting down to work.
- Reflecting on teamwork provides better insights into team cognition, which is critical to improving team performance [13].

3.2 Discussion about parameters and metrics

Once we got the list of parameters that make teams efficient, we discussed which metrics could measure these parameters. Table 3 presents the outcome of this analysis. In this table, we include some questions that helped us to identify metrics. In addition, we provide information on where teachers can find data, and indicate this with the following letters: Tr (Teachers report, that includes observation of teachers at lectures and laboratories); Dc (Documentation presented in the sprint review); Dm (Daily Minute reports); Sv (Survey that each group answer after each sprint); G (the Git repository where all programs and documents are stored); SR (observation during the sprint retrospective); B (the collaborative board); Sr (observation during the sprint review); and Bd (Burndown chart).

Table 3. List of parameters and metrics to evaluate teamwork

Parameter	Question	Metric	Where?
Autonomy	Have the team needed much help?	Nº of questions to the teacher	Tr
	Are the proposed solutions original?	Originality level (1-5)	Dc
Collaboration Dynamics	How many meetings has the team held?	Nº of daily scrums	Dm
	Are all the team members participating in the project?	Participation level (1-5)	Sv
	Are all team members improving the code?	Nº of commits per member	G
	Do students help each other when some member is stuck?	Times that a student have helped a counterpart	Dm
Internal communication	Are all members attending meetings?	Attendance degree	Dm
	Are there problems caused by communication failures?	Nº of problems	SR
	Are all members using the collaborative board?	Average number of contributions and std deviation	B
Conflict Management	How many conflicts have been solved during the Sprint?	Nº of solved conflicts	SR
	Do team members agree the way that conflicts have been solved?	Satisfaction degree (1-5)	SR
Team Cohesiveness	Is the task division equitation?	Points division (100 points to share among the team)	Sv
	How consistent is the team in completing the work?	Nº of user stories validated by the product owner	Sr
	Are all team members committed with the project?	Commitment degree (1-5)	SR

Role's distribution	Are team members changing roles with respect to the previous sprint?	Nº of members that have changed the role	Dm
	Are team members finishing assigned tasks?	Relationship task finished/task assigned	B
Planning and task division	Is there evidence of planning?	Nº of evidence and quality (1-5)	Dc
	Is task division efficient?	Nº problems originated by inefficient task division	B SR
	Are the user stories described adequately?	US description grade (1-5)	B
	Are the validation criteria correct?	Validation criteria grade (1-5)	B
Team Cognition	Are the team updating the burndown chart?	Yes / No	Bd
	Do the team know its velocity?	Deviation between expected and delivered user stories	Bd
	Are the team applying corrective measures?	Nº of changes applied from one sprint to other	SB

Teachers can select what parameters are adequate to measure in each project, depending on the course and the characteristics of the project. Moreover, working with these metrics will require implementing a feedback loop in parallel with the development of each sprint. The steps in this loop are presented in Figure 2:

- Collect data from the minute daily report, the collaborative board, the burndown chart, the documentation performed for the sprint review, etc.
- Measure: convert the gathered data into metrics to have an objective way to evaluate the teamwork
- Analyze: look for problems, formulate questions about the team, workflow, or process
- React: planning changes to implement in the next sprint to improve the teamwork

In each sprint, this loop is repeated to make adjustments that enable the team to enhance their work. Initially, teachers are responsible for collecting data and having the students analyze it. However, these duties are delegated to the students in more advanced courses.

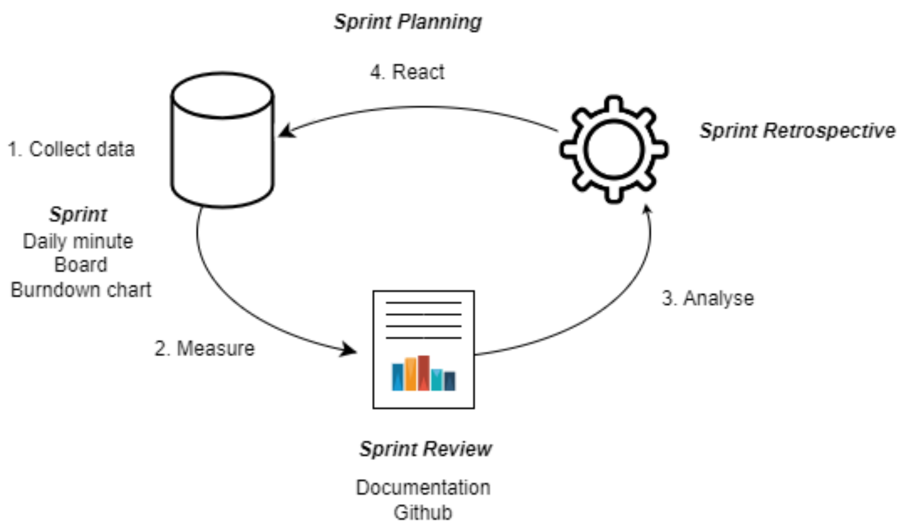

Figure 2 Process to collect and analyse metrics

3.3 Activity to compare teamwork performance

An experiment based on a classic team-building game, based on [26], was conducted to evaluate the method effectiveness. A total of seven groups of students, consisting of three groups from the first course and four groups from the fourth course, were given a problem to solve within a set timeframe.

The context of the experiment is as follows: our client, a large sports brand, wants to launch a non-existent marine sports product on the market. In order to give a more extraordinary image of innovation, this product will be sold through an automatic vending machine. It allows students to simulate the creation of the prioritized list of objectives (Product backlog), describe the user stories and the execution of the process itself. The product is implemented using paper, scissors, adhesive tape, balloons and ribbons. Initially, the teacher explains the activity presenting the instructions and the epic of the product. Afterward, groups meet to talk about the epic and could ask some questions to the teacher to clarify ideas.

Groups have ten minutes to compose user stories demonstrating an understanding of the given problem. These user stories provide insight into what tasks the product team needs to accomplish to create a successful product. Then, students have thirty minutes to implement the product, during which they must:

- Select which user stories will be implemented.
- Assign tasks to each responsible party.
- Execute the assigned tasks.
- Verify that the user stories were successfully implemented.

Finally, all products are exhibited, and groups present their creations.

Teachers decided to measure the following parameters from section 3.2: group autonomy, collaboration, internal communication, team cohesiveness, and the team's work planning. The rest of the parameters were not considered adequate to be measured with this activity. The metrics were obtained using those questions from Table 3 that were suitable for the activity. After obtaining the metrics, the average of those contributing to each parameter was calculated separately for the first-course groups and for the fourth-course groups and results were presented using a spider diagram.

4 RESULTS

Figure 3 presents the spider diagram for the first-course teams (fig. 3.a) and the fourth-course teams (fig 3. b). As can be seen by comparing these figures, the first-course teams have a lower degree of autonomy, internal communication, cohesiveness, and planning ability than those of the fourth-course teams. Nevertheless, the collaboration degree is similar in both groups due to the involvement of students in the activity.

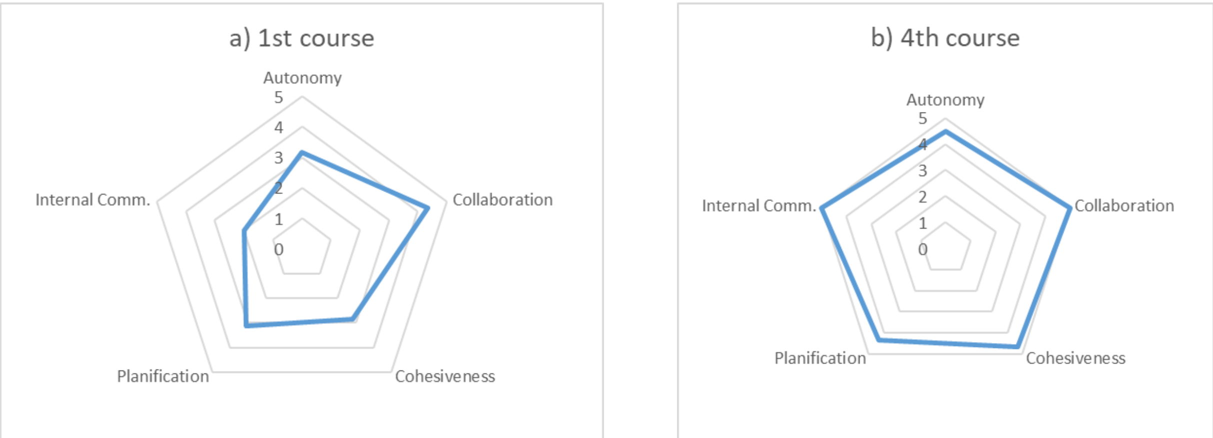

Figure 3 Activity results

Teachers have collected some observations during the activity, such are:

- First-year students struggle to create accurate user stories due to difficulty distinguishing between users. Furthermore, they propose some user stories outside the client's scope.
- Fourth-year students demonstrate remarkable efficiency when it comes to task division and prioritization. They are well-coordinated, work harmoniously, and excel at quickly organizing their work.
- Fourth-year students conduct a short technology assessment before beginning the implementation process.
- Women-formed groups create aesthetically appealing products.

5 CONCLUSIONS

ITD at UPV is one of the first university degrees in Spain to employ PBL as an instructional tool for teaching students how to create technological projects. The authors of this work have met to collaborate in order to perform a strategy to evaluate teamwork performance within the projects implemented in each semester, managed using Scrum. The contributions of this work are:

- A list of parameters that contribute to increased teamwork performance.
- A list of metrics to evaluate teamwork performance.
- A process to collect data that is intricate in the Scrum loop.

These contributions are interesting for teachers to evaluate teamwork, but also for students to manage their work.

This methodology's implementation results have been obtained by performing an activity with students for the first and fourth years. From this activity, we can conclude that students in their fourth year demonstrate more remarkable teamwork efficiency than first-year teams. This demonstrates that this methodology has been successful in helping students improve their skills throughout their studies.

Further studies are being developed to measure the student's progress over time, helping to evaluate the methodology's effectiveness.

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