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Applying Lean Concepts to Teaching and Learning in Higher Education: Findings from a Pilot Study*

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This paper presents an empirical study based on the application of lean concepts to teaching and learning in student centered learning environments. It is based on findings from a pilot study carried out within an engineering course at the University of Minho, Portugal. The aim of this research is to contribute to the development and consolidation of the field of lean education in Higher Education. The main objectives of this study are to describe the model developed based on the application of lean concepts to teaching and learning and to analyze students' perceptions in regard to the application of this new model in the course of ''Lean Enterprise''. For the application of the model, a pilot study involving 31 students, during 12 sessions of 100 minutes each, was developed. Data collection was based on online questionnaires to students, applied at the end of each class (for process evaluation) and also at the end of the conclusion of the course (overall evaluation). Findings based on students' perceptions suggest that the model applied was useful and contributed to improve the teaching and learning process, while at the same time promoted continuous reflection of practice by the teacher. Some recommendations for future applications and improvements of the model are discussed in the paper.

Keywords: lean principles; teaching and learning; project-based learning; PDCA cycle; curriculum design

1. Introduction

Lean philosophy is being applied with great success in many different fields such as industry, hospital, public services, distribution, offices, and so on. Since lean implementations are bringing very robust improvements to different stakeholders of organizations from many areas of economy, an opportunity is here to improve teaching and learning excellence using the same philosophy.

Lean teaching, here understood as the application of the principles and practices of Lean Management to teaching, specifically in the design and delivery of courses [1], is an emerging research topic that has gained increased interest by engineering teachers and faculty members who are interested in improving their performance and the quality of teaching and learning processes. This field becomes even more significant when an interdisciplinary approach is intended, matching engineering concepts to educational concepts of curriculum design, implementation and evaluation [2].

The main structure of the model is focused on the student (student centered) as well as in the fifth lean principle ''pursuing excellence'' or, in other words, the continuous improvement concept commonly applied in lean environments. As in lean philosophy where the client is the center, here in this proposed model, the student is also at the center. The continuous improvement concept is based on PDCA (Plan, Do, Check, Act) cycles supported by standard work concepts. Every cycle is planned, executed, and decisions on the next cycle is taken. The standard may be redefined by lessons learned from the last cycle. The aim of this paper is to present a model based on the lean philosophy and its most relevant concepts applied to the teaching and learning context. To attain this goal, a pilot study was carried out in the context of a course named ''Lean Enterprise'', which is part of the 5th year of the Integrated Master degree program of Industrial Engineering and Management (IME), at the University of Minho, Portugal. This is an optional course that is aimed at supporting students in the development of skills in the context of creating continuous improvement systems in companies and the application of concepts and Lean thinking in non-industrial processes such as lean office, lean accounting and in Lean leadership aspects. Applying concepts of lean thinking in the course makes a lot of sense since the course itself is about that.

The methodology applied in the case presented here is inspired in concepts and principles of lean thinking as well as in some tools that have been developed to help the materialization of lean concepts and principles. The model is also grounded on important educational concepts, such as curriculum development and the importance of an alignment

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between the most important dimensions of the curriculum planning: learning outcomes, teaching strategies and assessment methods.

2. Planning teaching and learning in higher education

Teaching and learning in Higher Education have gone through several changes in the recent years, mostly due to the implementation of the Bologna Process in the European Higher Education Institutions [12, 13]. Greater attention has been given to student centered learning and to active learning methodologies. In the context of Engineering Education, student centered learning has taken the form of project approaches [14–16] and other cooperative learning environments [17], which have changed the way students learn and also how teachers deliver the teaching and learning process. It is also important to highlight the importance of collaboration between students and the importance of creating cooperative learning environments that enable the development of these competences [27].

Student centered curricula require changes in educational activities, assessment tasks and strategies, and a change in the organization of learning. To attain these goals, teachers play a very important role in the teaching and learning process. First of all, the teacher is responsible for the course planning and also for its implementation and assessment. Besides this, the teacher also needs to develop strategies that allow a continuous improvement of performance and lead to his/her professional development. Reflective practice is, therefore, a crucial concept in Education that promotes teacher professional development and improvement [18].

Thus, the planning process is a very important phase in preparing teaching and learning. Three main components of the curriculum must be given special attention here [2]. These are: learning outcomes, teaching strategies and assessment methods. When planning a course, the teacher must bear in mind the following questions:

- What do you want your students to achieve at the end of the course? [learning outcomes]
- What kind of teaching and learning activities will foster the achievement of the learning outcomes that have been set? [teaching strategies]
- What kind of tasks and assignments can students do in order to demonstrate the acquisition of the intended learning outcomes? [assessment methods]

Biggs [19] refers the importance of an alignment between these three dimensions. In this process, assessment plays a key role as it influences what a student interprets to be the important learning outcomes for the course. Designing assessment methods that promote student learning include the use of several frequent tasks rather than one end of course assessment (or build in steps) and also providing timely and detailed feedback to students [20, 21]. Feedback is crucial for effective learning. Teachers must use feedback to evaluate how well the classes went and how they can be improved. Several sources of information may be useful here, such as student evaluations, open discussions with students, the teachers' own experience with the course, etc. All evidence collected from these sources can provide important inputs for improving the teaching and learning process. In summary, formative and continuous assessment processes should be used as a tool for learning [22, 23].

If we look at these concepts of curriculum development from a lean perspective, we can easily recognize the similarities with the PDCA cycles. However, in this brief presentation, we did not develop further on possible concept which is closely related to the last phase (ACT) of the PDCA cycle—action research or the concept of the "reflective practitioner". Both of these concepts, broadly known amongst educational specialists, suggest the last phase that is apparently missing. Action research is the process of using research by educational professionals to inform and improve practice, through a systematic approach aimed to change practice and promote professional development. There is an emphasis on critical reflection about practice. According to Creswell [24], action research includes four stages: planning, acting, observing and reflecting.

In the next section, an attempt to build a model for planning teaching and learning, based on the lean philosophy and its most relevant concepts, will be presented. This model is inspired by these educational concepts on curriculum development and implementation, which were taken in consideration when deciding the tools to apply in the pilot study.

3. Lean concepts

As the Toyota Production System (TPS), the Lean philosophy may be seen as being based on two basic concepts [3]: the first concept is the cost savings achieved by reducing production waste (activities with no value adding) and the second concept is treating workers as human beings and with consideration. In Lean context, waste is any activity that does not add value to products or services, assuming that value is assigned by the customer. There are 7 types of classic waste already defined in TPS [4]: Overproduction; Materials waiting (inventories); People waiting; Defects; Excessive or inappropriate processing; Transport; and Motion. Although the second concept (treating workers as human beings and with consideration) is central in any lean implementation and success very little attention will be given here in this document since in learning/teaching environments the concept of worker does not fit easily.

Lean approach to production is being applied with enormous success in many different areas of activity. Starting in industry in the decade of 1950 as the Toyota Production System [4] became known worldwide as Lean approach to production in the decade of 1990 through a famous book by Womack, Jones and Ross [5]. This approach is lean because it provides a way to do more with less human effort, less equipment, less time, and less space, while providing customers with exactly what they want [6]. To accomplish this, the approach is focused in the elimination of activities that do not add value to products as well as in using the full potential of people. The lean principles expressed by Womack and Jones [6] are:

- Value—the value must be defined by the customer since the customer is the one that will pay for the product.
- Value Stream—Identification of all the steps needed to build a product from raw material to the customer.
- Flow—the products should flow through the various process steps without interruptions or delays at the rate that the customers need.
- Pull Flow—nothing is performed without being required by the next process or by the customer.
- Pursuing Perfection—the organization needs to always find ways to improve, to do better and better all the time.

These principles are largely applied not only in industry but also in hospitals [7], in offices [8], in construction [9] as well as in other sectors of activity. Applying lean principles and concepts to the teaching/learning process is far from being easy. Lean thinking was developed in industrial environments with some particularities that do not exist in the classroom. The intangibility and complexity of learning processes make them difficult to be defined precisely and very difficult to measure their performance. For all these reasons the application of lean thinking in these processes becomes a very difficult task. Nevertheless, since lean thinking has been applied in more and more non-industrial environments, it also may bring improvements in teaching/learning environments. Emiliani [1] has already proposed a model for lean teaching where some lean principles are applied with success in the educational context.

A key lean concept applied in the experience documented here, is the continuous improvement. The continuous improvement model, often used in Lean environment to materialize the 5th principle of Lean (Pursue Perfection), is frequently based on PDCA cycles and the concept of Standard Work (Fig. 1). The concept of standard procedures or Standard Work [10] is based on the assumption that if an operation or set of operations is carried out always in the same way then the result is always the same both in terms of quality and in terms of time spent (important for planning).

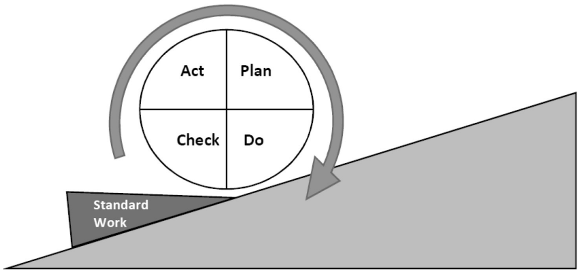

Fig. 1. PDCA cycle and Standard Work

Taking as its starting point an opportunity for improvement or a problem to solve a particular case, the PDCA cycles can be summarized as follows: (Plan) the current situation is clearly defined and a plan is developed in order to make the desired change; (Do) the plan is executed to reach the desired state; (Check) verifying if the results is what was expected or not; and (Act) a decision taken about what to do in the next PDCA cycle. A new cycle will then be initiated. The PDCA methodology only works effectively if there is a default rule or procedure (Standard Work) assumed for the case in which the PDCA cycles are applied. Whenever the PDCA cycles result in an improvement then the standard procedure should be updated to ensure that the gains are maintained (see Fig. 1). Another relevant concept is creating flow (third lean principle). Flow is based on a likely unintuitive aspect of Lean thinking. The act of processing products in batches is naturally seen as a way of reaching high performance but that is not exactly true. Batch processing is the opposite of flow and in lean approaches flow is required as much as possible. Flow is achieved when products flow continuously along the system processes.

The desirable limit of flow is called "One Piece Flow" which in fact reflects perfect flow since the items (products, parts or components) never wait to be processed, advancing from process to process in a perfect rhythm. Fig. 2 shows the lack of flow (left side of diagram) where there is water stagnation at some points along the process while the right side in the same figure shows flow, where the water flows continuously along the river bed.

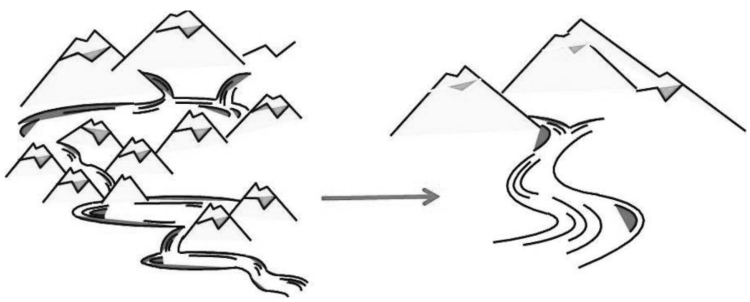

Fig. 2. Flow concept [11].

4. Methodology

As mentioned previously, applying lean principles and concepts to the teaching/learning process is a difficult task and, therefore, also a new research area. According to this, the present study aims to provide answers the following research questions:

- Is it possible to apply lean principles to the classroom context?
- Is it possible to apply lean principles to the teaching and learning process?
- Can the application of lean principles contribute to improve the teaching and learning process?
- To what extent are lean concepts and practices suitable for the educational context, namely, the classroom environment?

Based on these guiding questions, the main objectives of this study are:

1. To design a model based on the application of lean concepts to teaching and learning in higher education;
2. To apply the lean teaching and learning model in the course of "Lean Enterprise" at the University of Minho;
3. To analyze student's feedback in regard to the implementation of the new model and its effectiveness.

Data collection was based on questionnaires to students, applied at the end of each class (for process and product evaluation) and also at the end of the conclusion of the course (overall evaluation). For the evaluation of the process, students answered an online questionnaire at the end of each class. The questionnaire was based on a Likert scale and included seven criteria concerning the teaching and learning process. Some of the variables under study in this research included student involvement, teacher's role, student assessment, teaching strategies, learning outcomes, significant learning, feedback and punctuality. The questionnaire was applied in all sessions, except the first and the last session (10 out of 12 classes). Besides this, the product evaluation was based on collecting feedback from students in regard to their performance on the online group tests, oral presentations and the punctuality grading system. For the overall evaluation of the course, students were again asked to answer a final questionnaire, at the end of the 12 sessions, based on their opinion in regard to the course and to the new model based on the lean concepts applied to the teaching and learning process. This questionnaire included 9 questions based on a Likert scale (six of these questions were followed by an open field where students were asked to justify their answer) and 2 final open-ended questions: (1) identify the most positive and less positive aspects of the course and (2) other comments or suggestions.

For data analysis, descriptive statistics (average results) was used to describe and discuss the quantitative data achieved in the questionnaires collected from students. This analysis was complemented with simple graphics that allowed a better understanding and comparison of results from different items included in the questionnaire.

5. Lean Teaching and Learning (LTL) model

To better describe and understand the Lean Teaching and Learning (LTL) model, the next section presents the model's development, implementation and evaluation. An attempt to clarify the connection between the lean concepts and their synonymous in the teaching and learning process is provided on Table 1. These examples of lean concepts and their related concepts in the educational field can allow a better comprehension of their adequacy for the LTL model proposed.

5.1 Development of the LTL model

For the development of the Lean Teaching and Learning (LTL) model, several tools were selected in order to apply the main Lean concepts to the teaching and learning process, namely, continuous improvement, identification of value, flow, "Mura" and "Muri", people waiting Waste and Low cost automation. These concepts are summarized on

Table 1. Lean concepts and tools applied

Lean Concept	Teaching and Learning Aspect
PDCA	Action research
Product	Learning outcomes
Pursue perfection	Continuous improvement
Value	Effective learning; significant learning;
Waste	Ineffective learning
Value stream	Tasks/actions developed to achieve the learning outcomes
Flow	Continuous assessment; timely feedback; monitoring the learning process; self-regulation of student learning
Pull flow	Taking in account student's needs and interests to organize the teaching and learning process
Focus on the customer	Focused on the student (student centered)
Respect for people	Teacher's as facilitators; student centered
Low cost automation	Online resources to support teaching and learning, quick and easy access to class materials and information; eLearning; online tests, etc.

Table 2. The expression "Mura" and "Muri" are Japanese words commonly used by lean practitioners referring respectively to workload imbalance and overload.

The fifth principle of Lean (*Pursue Perfection*) was the most important lean concept applied which is associated to PDCA cycles and Standard Work. It plays the main role because the teaching/learning process itself is based on it. There is an attempt to identify Value (first principle of lean) by the mechanism of inquiries at the end of every class and at the end of the course. The results are not very clear since the concept of value in teaching/learning processes is not easy to specify.

Flow is achieved because as soon as new knowledge is added in the class, the students have to experience it, discuss it and then be tested about it. Flow is also promoted in the project that students have to do out of the classroom. Every week teams present the status of the project eliminating the accumulation of project tasks waiting to be performed during long periods. Another lean concept known as *"Mura" (meaning imbalance)* can also be achieved by students having to do some work every week instead of doing either nothing in some weeks and then a lot of work at the end of the course.

The punctuality grading (15% of the final grading) allows that, at the beginning of the class, *people waiting (waste)* is completely eliminated. Students that for some reason cannot comply with punctuality then this 15% is assigned to the testes and project. Other cases of people waiting during the class were not addressed in this project.

Low cost automation is another concept associated to lean thinking that is also applied in this model. The online group tests and individual questionnaires, as well as some automatic processing of data, were introduced in this course with the same gains in teacher's time. Nevertheless, many other low cost automation possibilities are still to be developed and used.

Table 2. Lean concepts and tools applied

Lean concepts	Tools	Level of application
Pursue Perfection or Continuous Improving	PDCA cycles and Standard Work Online Questionnaires	High—applied as the main structure of the learning/teaching process
Identification of Value	Online Group Tests Oral Presentations	Low—the definition of value was not very effective
Focus on the customer	Student centered learning. Student involvement. Student checking	High—All methodology is focused on the student
Flow	Assessing in every class and project presentations every week.	Medium—the project part of the course had some accumulation at the end of the course
"Mura" (imbalance) and "Muri" (overload)	Assessing in every class and project presentations every week.	Medium—Since most work was performed in teams some students may had more work than others
People waiting Waste Respect for people	Punctuality grading	Medium—applied only in one case of waiting waste
Low cost automation	Online Group Tests Online Questionnaires (individual)	Low—many other low cost automations may be applied

Table 3. Standard Structure for 100 min class

Introduction (5 min)	Discuss the evaluation results collected from students in the previous class Remember key points from the previous class (using visual information) Present the class plan to the students Identify the student learning outcomes for the current class
Execution (60 min)	Activity 1 (~30 min) Presentation of material or group work (active learning). *Note that even presentation of material also must incorporate active participation of students.* Activity 2 (~30 min) Group work if activity 1 was presentation or the other way around.
Evaluation (15 min)	Product evaluation—Groups of 3 students perform a test to verify the learning outcomes achieved. During the test, the students in each group will discuss and learn with each other. Process evaluation—Students will respond to a questionnaire (see Table 2).
Student presentations (15 min)	Each team presents the work performed since the last project presentation. Feedback is provided by the teacher and by other students. This project work is assessed.
Conclusion (5 min)	Open discussion on lessons learned, improving opportunities and next steps.

The main structure of the methodology is that in each class a PDCA cycle of continuous improvement is performed. A set of standards should be created at the start to make the continuous improvement effective. One of the standards created was the standard structure for the class (see Table 3). The classes follow a pattern established of 100 minutes per class with a defined instant to start and a defined instant to finish. The PDCA for each class should be based on the following guidelines:

- Plan—The class is planned to comply with the standard structure. Presentations are prepared as well as active learning activities and online tests. This planning phase is important to ensure that there will be space for the active participation of students in a significant part of the class. The times, once planned should be followed as rigid as possible. If during the class, the plan fail to be followed, this must result in a more detailed planning for next classes.
- Do—The class is performed based on the previous plan. It is important to keep a relatively strict control of time.
- Check—This phase is used to evaluate the product (the results) as well as evaluate the process. Regarding the product evaluation, an online test is submitted to teams of 3 students whose composition changes every class. This test has two functions. The first one is for students to discuss the issues in order to share lessons learned and consolidate knowledge. The second one is to evaluate the product (whether the learning objectives were achieved). Regarding the evaluation of the process the students are asked to answer an online small survey to assess the process.
- Act—Based on the results obtained through the evaluation of the product (test in teams of students), the evaluation of the process (the survey results at the end of the class), the students inputs from the open discussion at the end of the class, and from the teacher's own perception of learning activities, decisions are taken in order to adjust the standards or other practices in order to improve the next class.

The applied mechanisms to assess the students were created to be aligned as much as possible with the learning objectives, learning effectiveness and also to follow Lean principles and concepts. The classes are the most important learning moments but extra class activities are also expected to be part of the process. Each class is self-contained in a way that the learning outcomes are taught, experienced, discussed and tested. In lean thinking this is aligned to the flow principle since the students do not have to be tested on these learning outcomes later in the semester. The extra class learning activities are assigned to a project where the knowledge is applied. In the project the team of students must present every week on how the project is developing. The teams receive feedback and tips to keep going with the project. This is also a way of materializing the lean principle designated as "Flow". The wastes such as overproduction and inventory are also reduced with the creation of flow.

The final grades are obtained by adding 40% of the project grade with 45% from the written tests and with 15% of the punctuality grade. The punctuality grading works as two important lean concepts: the elimination of one type of waste which is "people waiting" and the respect for people.

5.2 Implementation of the TLT model

For the application of the model, a pilot study was carried out by one of the authors of this article in the

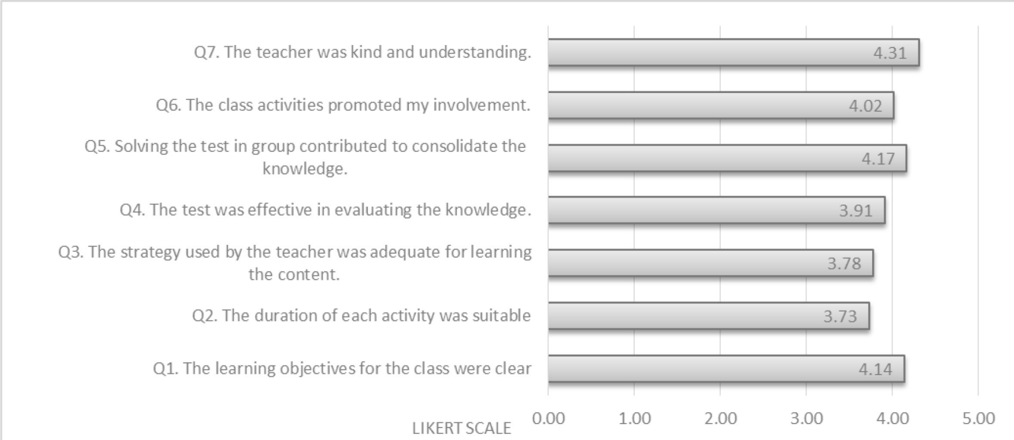

Fig. 3. Average results obtained from all questionnaires submitted at the end of every class.

context of a course named "Lean Enterprise", which is part of the 5th year of the Integrated Master degree program of Industrial Engineering and Management (IME), at the University of Minho, Portugal. This is an optional course that involved 31 students. The students were male and female regular students aged in general from 22 to 24 years old. Only 2 of them were a bit older and having part-time jobs. Classes took place during September and October 2015. During the 6 weeks of the course duration, there was room for a total of 12 sessions of 100 minutes each. The aim of this course is to help students develop skills in the context of creating continuous improvement systems in companies and the application of concepts and Lean thinking in non-industrial processes such as lean office, lean accounting and in Lean leadership aspects. Applying concepts of lean thinking in the course makes a lot of sense since the course itself is about that. The methodology applied in the case presented here is inspired in concepts and principles of lean thinking as well as in some tools that have been developed to help the materialization of lean concepts and principles. The main teaching and learning strategies used in class were based on active learning principles, such as the use of project work, group activities, oral presentations, games and simulations, exercises, debate/discussion, amongst others.

5.3 Evaluation of the LTL model

In this section, results will be presented and discussed according to three main topics: process evaluation from the PDCA cycles, product evaluation and the overall evaluation of the course by the students.

5.3.1 Process evaluation from PDCA cycles

At the end of every class, the students were asked to give feedback about the class performance. The global average results from all classes to all 7 questions is presented in Fig. 3. The questions with average results above 4 ("agree") were Q1, Q5, Q6, and Q7 being "Q7—The teacher was kind and understanding" the question with the best average result (4.31). It may suggest that the "respect for people" concept associated to Lean Thinking was particularly recognized by students. The question with the second best result "Q5. Solving the test in group contributed to consolidate the knowledge" suggests that students appreciate being involved in group work discussing different points of view. This is also linked with lean concepts since it is associated to team work and the respect for people.

On the other hand, the question "Q2. The duration of each activity was suitable" (3.73), followed by the question "Q3. The strategy used by the teacher was adequate for learning the content" (3.78), and "Q4. The test was effective in evaluating the knowledge" (3.91) are the questions with less positive results.

When analyzing the results of process evaluation with the effect of PDCA cycles, the progress from class 1 to class 10 regarding the questions Q1 and Q7 are presented in Fig. 4. It can be said that the PDCA cycles worked in a very controllable way regarding question Q1. At a certain point, the teacher had to reflect upon the way the learning outcomes were stated since the feedback from students was getting less positive from class 1 to class 5. Putting more attention on how the objectives were stated resulted in improvement of student feedback from class 5 to class 10.

Monitoring the question Q7, was not very easy since it was not always evident for the teacher what type of behavior would lead to be regarded as being kind and understanding. This is a learning process that takes time to be mastered.

Figure 5 shows two cases of the decreasing of

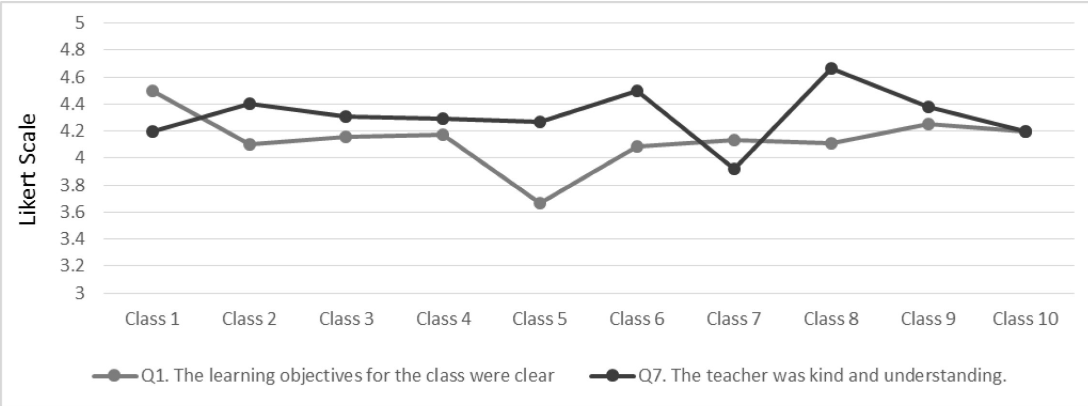

Fig. 4. Evolution of results for questions Q1 and Q7.

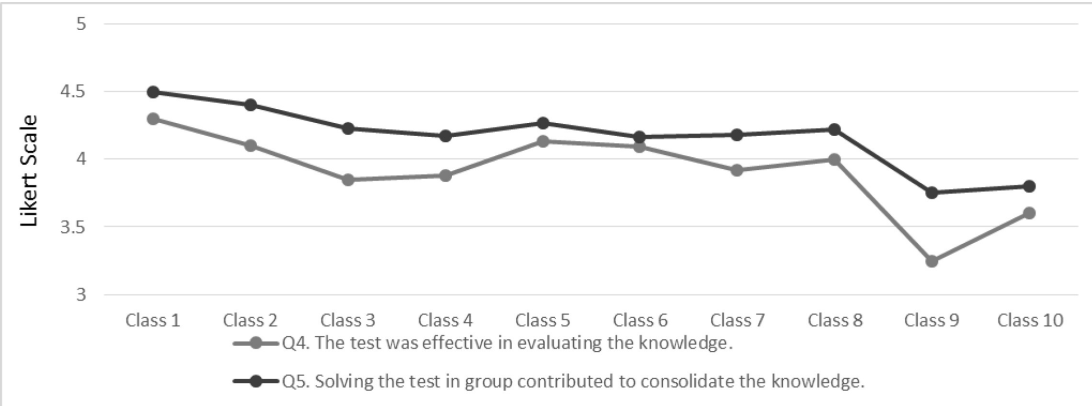

Fig. 5. Evolution of results for questions Q4 and Q5.

students' ratings in regard to the online group test. Difficult control was perceived by the teacher in regard to this. During the PDCA cycles, although perceiving the decline of results, the teacher was unable to invert its tendency.

Another relevant result is related to the strategy adopted for each class and the duration assigned to each activity (see Fig. 6). Regarding question Q2 "The duration of each activity was suitable", students' feedback from the first three classes was poor, specially second and third classes with negative results, below 3. The teacher reacted to this poor performance and found ways of preparing better plans for the following classes.

Finally, as also shown in Fig. 6, the performance behavior of question Q3 and Q6 is similar. This similarity indicates that apparently, students consider the classes in which they are engaged in activities the classes with better strategy. Class 2, 8, and 10 had longer passive learning and class 6, and class 9 had longer active learning where students were involved in activities such as games or

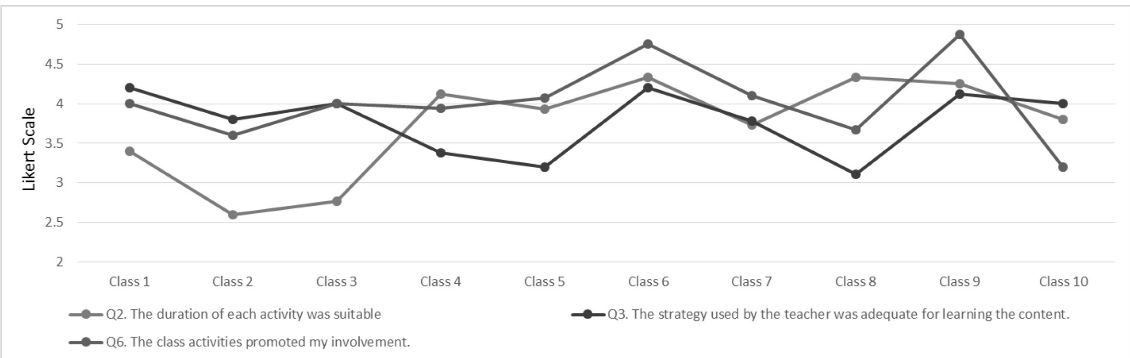

Fig. 6. Evolution of results for questions Q2, Q3 and Q6.

group experiments. This is an interesting result although could only be recognized at the end of the course. This finding can, however, be useful in planning the next courses.

A final remark can be drawn from the teacher's perspective towards the PDCA cycles. Improving class performance from class to class is not an easy task mainly because of two reasons:

In the beginning students are very positive with this new methodology and tend to be less demanding but they gradually become more and more demanding as the weeks go by. To keep the same performance (feedback) the classes must improve.

Difficulty in pursuing different performance indicators at the same time. This is aligned to what Rother [25] stresses in his Improvement Kata methodology where the improvements are based on very small daily steps and focusing only on one performance indicator each time.

5.3.2 Product evaluation

In every class, there was room for student assessment regarding punctuality, testes and project presentations. Punctuality was included to assure that the class would start at the defined instant and hence improve the use of class time. Fig. 7 shows the number of students present at the exact class starting time from class 2 to class 12. In the first class, there wasn't punctuality assessment because in that first class the students were not aware of that assessment criteria.

As you can see in Fig. 8, the number of students on time was 24 on class 2 and 23 on class 3 but then the number increased to a number between 28 and 31. These two first classes were used by some students to actually learn how the system really worked. This punctuality grading in every class clearly helped in avoiding people waiting (one type of waste) and helped in using all 100 minutes time assigned to each class.

Another product evaluation tool was based on group tests at the end of each class. This group test engaged the students in discussions about the subjects being tested and worked very well as the students were 100% actively involved. Although the tests were used to assess the students, they

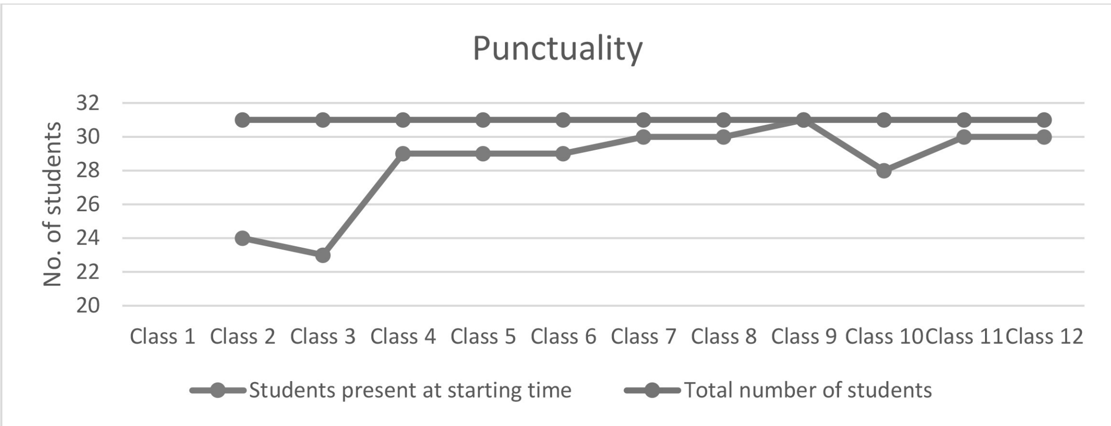

Fig. 7. Evolution of the number of students on time.

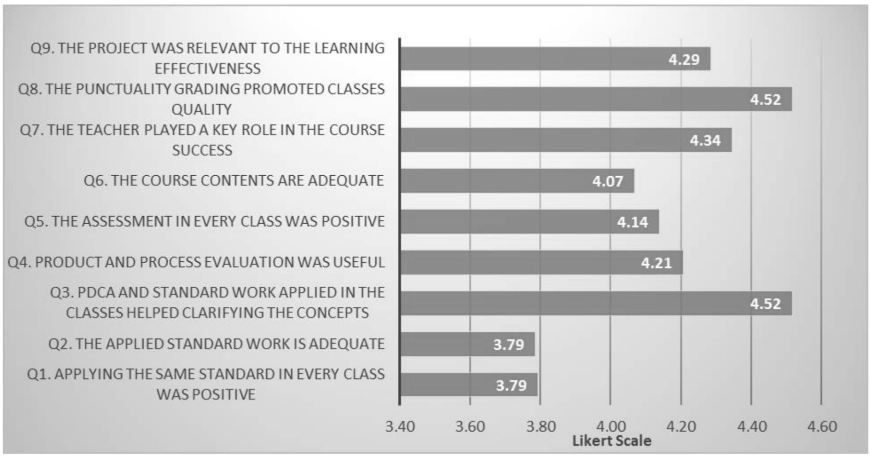

Fig. 8. Average results obtained from the final Questionnaire.

mainly worked as a way of getting the students involved in clarifying concepts and discussing points of view. Since the group composition changed every class, the students had to deal with different methods of decision making.

Finally, the project work presentations in every week forced the groups to move every week a step further in their projects. Since teacher feedback was also focused on the progress performed on the project, these PDCA cycles helped in creating flow (third lean principle).

5.4 Overall evaluation

At the end of the course, all 31 students answered an online questionnaire whose results (averages) are presented in Fig. 8. A Likert scale was adopted to collect the answers that could go from 1 (strongly disagree) to 5 (strongly agree). One of the questions with the highest scores (4.52 out of 5) was "The punctuality grading promoted classes quality". The students appreciated the fact that all students were in the classroom before the starting time and therefore the class time was effectively used. The reason was that 15% of the final grading system was based on punctuality. Interestingly, the students appreciated it. The other question with the same high score was "PDCA and Standard Work applied in the classes helped clarifying the concepts". In fact, the main structure applied in the classes is based on PDCA cycles and Standard Work concept and students recognized its application and usefulness.

On the other hand, the answers with poorest score were "Applying the same standard in every class was positive" and "The applied standard work was adequate", both with 3.79 out to 5. This finding requires greater reflection and deeper understanding on how to improve and redesign the class structure standard in order to be more effective and satisfy students' needs.

In this questionnaire, several of the questions also had an open ended field, where students could complete their answers with written comments. Interesting comments regarding the question "The assessment in every class was positive" and the question "Product and process evaluation was useful". One frequent type of comment was related to the discussion created during the online group test performed in every class. Many students stressed the value of the discussions as an effective learning tool. Comments such as "allowed exchange of points of view", "developing capacity of working with different people", "helped consolidating knowledge". Other comments were: "worked as a class conclusion and clarification of key points" and "a good way of keeping students aware during the class". The lean concept of flow created by the assessment system was also recognized by students, as one student confirmed "the tests in every class avoided accumulation of work".

Student assessment is always a critical issue and hardly the system appeals to everyone. Students that usually achieve high grades in written testes do not feel very happy with the system applied in this course. These findings are consistent with previous research based on engineering students' perceptions about assessment methods and their fairness, especially when active learning methodologies are implemented [26]. These learning approaches recognize the importance of other competencies, besides the technical skills and knowledge, such as teamwork, communication, decision making, problem-solving, time management, etc., which are taken in consideration in these "student-centered" assessment models. The group component is favored in regard to the individual component.

6. Conclusions

Based on findings from this empirical study, it is possible to draw some conclusions in regard to the application of lean concepts to teaching and learning in higher education. First of all, the results suggest that lean principles and concepts may bring benefits to the educational context. This is a recent and emerging field of research and, therefore, this study brings some important insights for its development and consolidation in higher education.

The model used, based mainly on the PDCA cycles, promoted continuous improvement on the basis of weekly feedback from students (process and product evaluation with online questionnaires). Without this component, aligned with the concept of standard work, it would be very difficult for the teacher to identify the areas for improvement. So, the existence of a pattern for each class, for example, allows the teacher to focus on the specific areas that require further reflection. This also implies giving students an important role in the learning process, as they will be the main source of information to introduce improvements.

Data collected from students confirm these findings. Students clearly recognized the advantages of being actively involved in the classes and that having a standard work plan for each class allowed them to be better prepared and to know what is expected from them. In this way, students can optimize the time spent in class with significant learning activities and assessment tasks. The fact that students were assessed at every class also contributes to the idea of flow as well as the minimization of "Mura" (imbalance) and "Muri" (overload). From an educational perspective, this can be seen as very positive too, as feedback is the key for improving learning and students have the opportunity to reflect upon their performance and also request greater support from teachers in certain topics less understood. The concepts of continuous and formative assessment are clearly visible here and somehow match to the ideas of flow and continuous improvement from the lean perspective.

The punctuality system adopted in this experience assumed a great deal of importance to enhance the quality of classes. Students strongly agreed on this fact (see question Q8 on the overall evaluation results). This concept represents the respect for people, an important lean concept, as it avoids people having to wait for others. In the educational context, this means, for instance, the teacher having to wait for all students to be in class in order to start the lesson. This can be seen as very frustrating for those students who arrive on class at the starting time and are forced to wait until all the students arrive. The other idea implicit in the punctuality system is to avoid one of the seven types of waste in lean (people waiting). In our study, these concepts were fully applied and met. The weight assigned to punctuality was however perceived by the teacher as exaggerated so this number will be reduced in the next courses.

Findings from both process and product evaluations are aligned. Group work, through online group tests at the end of each class, were seen by students, in the overall evaluation, as an effective strategy to promote learning and also to summarize the main concepts discussed in class (achievement of learning outcomes). The concept of low cost automation very much associated to Lean was also used for the online tests and some automatic grading. During the process evaluation, this is, data collected at the end of each class, the students referred that solving the test in groups contributed to consolidate their knowledge and that the activities developed in class promoted his/her involvement. This is a very positive result showing the positive impact of group tasks and discussion on student learning. Besides this, the role of formative assessment strategies, which provide students with on time feedback, are also important. It is not just about achieving a grade, it is about having the opportunity to discuss and share ideas with others and build knowledge together.

Finally, the study also provided information on important areas to be explored in future research. The tools used to collect data (online questionnaires) should be revised and improved. The items included in the questionnaire are crucial for obtaining feedback. Therefore, careful attention must be given to the items included in order to reflect the main topics that can be subject of improvement. Some inconsistencies in student's perceptions also need to be explored deeper, using a qualitative research approach to better understand their meaning. This is an effort to improve the identification of value which is a key issue in Lean approach. Also, given the limitations of self-reported data via questionnaires, data collection obtained through other means could be useful to support the triangulation of the results.

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