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Learning through a Multiple Approach Competing Practical Exercise—MACPE: a Case Study with a Teacher's and a Student's Assessment*

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A Multiple Approach Competing Practical Exercise (MACPE), is an open exercise that confronts a group of students with a practical engineering problem using their own resources and choosing among multiple approaches in a competing environment. A case study with a teacher's assessment and a student's assessment has shown that this sort of exercise is able to motivate the students' learning process. It has also been found that it is a fun way to foster team work and constitutes an open door to innovation.

Keywords: student competition; practical case study

1. Introduction

The objective of the teacher's task is the student's learning. Several studies in literature highlight the connection between a student's engagement in a course and the student's learning process [1]. The resolution of a problem, as if it were a game, can be a good attempt to reach this goal, especially in engineering courses where the theory lessons play a predominant role.

Many study cases of educational projects to foster students' learning can be found in scientific literature. Many of those case studies are based on a case study methodology, others are project-based learning cases and most of them belong to the broader case type: problem base learning. An overview of problem based learning can be found in [2]. All those methodologies are learner centered approaches, collaborative and based on self direction [3–4].

Many articles also conclude that active learning is often effective for the student's learning process [5]. In general, student centered approaches are effective from the student point of view because they keep in mind the student's learning styles and not only the teacher's style as is well expressed in [6]. There are many initiatives for active learning: small breaks during the lecture in order to discuss and solve small issues, small projects common to several courses [7], home assignments to be presented orally and written, works based on virtual labs [8], final year group projects [9], open problems to be solved individually or in groups, problems based on a project-based learning or problem-based learning methodology.

This paper presents a case study that may be included in the category of problem based learning and that has some characteristics that are interesting for an engineering course in order to promote a deeper understanding of the content of the course and, at the same time, to help acquire additional experience that is important for an engineer, such as the capacity to collaborate, to take initiative, to decide among several possibilities, and to develop self knowledge, commitment and engagement. In addition, it was a fun experience for the students, not only in the preparation of the project, but also on competition day where the devices from each group were tested.

It has been observed that the competition was a source of fun and engagement for the students and provided a different way to think and work in the course. It is not the intention of the authors to claim that the courses should be centered on this type of exercise, or that this kind of exercise should be done in every engineering course. The intention behind this paper is to present a case study of an exercise that may work in engineering courses with a high degree of applicability. A double assessment is offered including, on one hand, the point of view of the teacher, and on the other hand, the perspective of the student. The objective of each of the assessments has been explained in [10].

2. Educational approach

What do companies demand from engineers? What is taught in a Mechanical Engineering degree? The relationship between the answers to these two questions is becoming more and more important. Companies often demand people be, not only well prepared in engineering, but that they also be able to work in a team, open to innovation and able to face problems on a theoretical basis as well as at a practical or executive level. It is clear that an en-

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gineering degree can not be based only on MACPEs like many MBAs are based only on the Case Method. But it has been found that the use of MACPEs is a convenient way to take teaching further and to foster the above mentioned abilities demanded by companies.

A MACPE, is an open *exercise* that confronts a student with a *practical* engineering problem using their own resources and choosing among *multiple approaches* or ways to carry out the task. Several student groups have to solve the proposed exercise in a limited time frame, *competing* against each other. Little time is required by the teacher to prepare an exercise of this type. This includes basically four stages: conceptual definition of the proposed problem, some previous experimental tests to check its validity, creation of an easy computational environment for data acquisition and post-process, and finally, the promotion of the contest using web resources.

A case study that would implement the previous approach needs some basic characteristics such as those shown in Table 1. For example, there are some limitations but the way to carry out the exercise involves as many degrees of freedom as possible and some gaps are left on purpose in an attempt to promote innovative solutions. The different groups can select their own approaches to the problem and all the doors are open to solve basic theoretical or practical problems in a multidisciplinary environment. Both competitiveness and team work are sought through a kind of public game with a final ranking where different groups have to compete against each other to win by coming up with the best design. A real engineering problem will always be proposed that will require some technical or practical skills that usually are not taught or applied in the classroom. A lot of practical complications will arise making the construction of the theoretically ideal device difficult.

3. Collaboration vs. competition

MACPE may be defined as a sort of PBL (Problem Based Learning) in which collaboration and competition coexist. This also happens in the real world in which there is competition between companies to elaborate the best project. But the project is normally carried out by a team, and therefore teamwork is needed.

There is competition because the grade depends on the position in the ranking. Competition fosters no help between teams. Actually, the first groups made very different designs; there was no exchange of ideas between the groups. It is believed that without the competitive feature, ideas would have been copied and students would not have learned as much. Competition also resulted in a fun experience. To test each of the devices took a few minutes and even though it was not compulsory to attend the tests, almost everybody from the groups attended because they wanted to know how the ranking was changing due to the new results and new positions in the ranking.

On the other hand, collaboration was also fostered due to the team work within each group. Team work was something to be encouraged and therefore it was decided that the MACPE had to be done by groups of students. Since the task was not very complex, it was decided that groups should consists of three students (although groups of two students were admitted). The result was positive and it seems that there was enough work for each of the group members. It may be highlighted that the two student groups obtained worse results than those formed by three students so it seems that at least three students were needed for this exercise. In general, the right number of students, in order to get a good quality collaborative task, will depend on the complexity and duration of the task.

4. Other types of learning's

MACPEs, as mentioned above, try to foster learning through a learner-centered approach. The student learns engineering content as will be explained in the section 'student's assessment'. However, this section shows other kinds of 'learning' that are achieved with these types of exercises.

Table 1. Characteristics of a generic MACPE type case study

Character	Meaning	Characteristics of a Case Study
(MA)	Multiple Approach	• A lot of degrees of freedom imposing fewer limitations. • Holes in the established limitations. • All kinds of analytical, numerical and experimental analysis are allowed. • Open access to teachers, laboratories and manufacturing areas.
(C)	Competing	• The final mark will be based on a ranking. • The proposed solutions are tested in public competition. • Groups of students are required.
(PE)	Practical Exercise	• Objective: to solve a practical real engineering problem. • Some manual or technical abilities will be required.

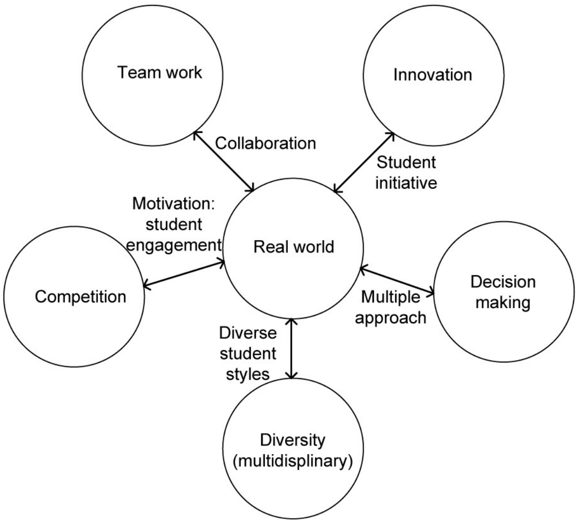


Fig. 1. Features and aptitudes in real world engineering.

In Fig. 1 some features of the real engineering world (team work, innovation, decision making, multidisciplinary work and competition) are related with the aptitudes that industry demands from future engineers (capacity to collaborate, self initiative, decisiveness, self knowledge, commitment or engagement).

First of all, collaboration is a must for this exercise to go well. Secondly, student initiative is part of the project and is open to ideas that leave aside the limitations of the exercise in order to innovate. Thirdly, multiple approaches due to an ill-structured exercise are a way to force the students to make the right choices from among several possibilities to solve the problem. Fourthly, the exercise makes the students aware of their own style or capabilities and therefore self-knowledge is acquired. And finally, the competing feature of the exercise gives a motivation to the student that engages in a deeper way with the task.

5. Student engagement

Students are different, with different attitudes and aptitudes and therefore are attracted by very diverse things. Some of them want challenges, others innovation, some to secure a good grade, some are good with their hands while others are good at working things out through simulations. A MACPE, as in general with exercises based on project-based learning or problem based learning, is a student-centered approach that provides incentives to a variety of students due to the multiple steps or aspects that are involved. A MACPE has many ingredients and it is therefore easy for each student to find some point of interest and this is effective from a learning point of view. A learning point of view that is not reduced only to apply theory to a particular problem but also other important lessons like team work skills, critical thinking, decision making and in general student initiative.

One student wrote in the questionnaire: 'It is interesting; it is another way to see problems similar to those that we solve during the course, and it is clear that there is a relation between the theory and the exercise'. This student also believes that to apply the theory to something else is interesting and therefore a source of engagement. 'Another way' and 'interesting' are expressions that mean that they are not used to working with this kind of exercise and they actually see in the MACPE a more original, and therefore, more interesting way to see the heat transfer syllabus.

6. The task

The rules listed in Table 1 were followed to prepare a simple case study to be solved by the students in a period of one week. The exercise was proposed to the students as a voluntary practice to obtain some extra points in a Heat Transfer course, which is mostly a theoretical subject. The students formed groups on their own having an upper limitation of three students.

The practical problem has to be solved as a small engineering project and consisted of designing and building a heat sink device around a stainless steel vessel or container to optimize its refrigeration by natural convection. The objectives and limitations were clearly explained and deadlines were established in a short document that was delivered in the classroom. After a few days to think about it, identical vessels (dimensions: diameter = 75 mm, height = 120 mm) were delivered by the teachers to the different groups. The students had to design, construct and test their refrigeration devices on their own in 5 days time, out of class hours. The teachers answered all the doubts posed by the students during these days giving general ideas and orientation.

All the modified steel vessels were handed and tested in front of the students in the same day during a practice class. Four testing platforms were prepared to check out four designs simultaneously and results were shown in real time on a big screen in conjunction with a global figure of merits. Boiling water was poured inside the mug and the water temperature was measured at the beginning (T_{ini}) and after five minutes (T_{fin}). Based on those two temperatures in conjunction with the surrounding temperature (T_{amb}) an objective evaluation of proposed solutions can be easily made using equation (1) which evaluates the cooling level:

$$Cooling = \left[1 - \frac{(T_{fin} - T_{amb})}{(T_{ini} - T_{amb})}\right] \cdot 100[\%] \qquad (1)$$

7. The competition day: a special sort of lesson

Even though that it was not compulsory to attend the testing of the rest of the devices during the competition day, everybody stayed to watch the evolution of the other teams. This live experience was a very interesting lesson and it has actually been decided that the attendance for future competitions would be compulsory. Indirectly, the competition allows the students to perceive a lot of extra information that are difficult to obtain by other means.

On that day there were no explanations. Students saw the prototypes from the rest of the groups, either for curiosity to see the design of the prototype or to see the result of that prototype in comparison with their own one. Then, discussions arose each time that four devices were tested on the test platforms and those discussions were centered on trying to figure out which was the best design every time the measurements started based on how the prototypes were built. This way, some basic concepts can be assimilated based on observations more than explanations, and students were encouraged to analyze the successful designs and failed attempts. Observing the figures of merit of each device and the device itself, students learned. It is believed that the ongoing discussion and observations were very enriching and they learned through experience instead of through explanations. One of the students wrote in the questionnaire: 'It was a good idea to make it a competition and a lot of fun'. This comment clearly represents the atmosphere of the contest day, a truly fun day that the students enjoyed as can be seen in Fig. 2.

Fig. 2. A picture taken during the competition day.

8. Teacher's assessment

The objective of the teacher's assessment is to analyze whether or not the proposed case study was able to make the students work all the different aspects of the MACPE that have been previously outlined. The students have to hand in a mandatory report of about two pages to access the practical evaluation of their design. The contents were not guided but there was a clear indication showing that they have to fully justify all their decisions, problems and the adopted solution. These reports have been systematically evaluated, not according to the contest classification, but in terms of the criteria proposed in Table 2 to also check if there is a relation between the results obtained by the students, given by equation (1) which determines the position in the ranking (and the grading), and the contents of their reports. The importance that has been given to each criterion is obviously subjective but it has been estimated that it represents quite well the quality of a given report between 0 and 10 points.

The voluntary participation in the practice was of 76 students divided into 28 teams. The composition of the teams was of 60 students in groups of three (78.9%) and 16 students in groups of two (21.1%). Students clearly preferred groups with as many members as possible, which is quite logical taking into account that all the members in a group would obtain the same reward.

Although not all the students succeeded in transmitting the virtues of their work, the best reports coincide with the best final results as shown in Fig. 3. If a division of the ranking in three different levels is proposed, the averaged quality of the reports is of 1.8 for the lowest, 3.7 for the middle and 5.7 for the highest. This is indicated by the background in Fig. 3. This fact indicates that, in general, the student teams that have proposed better designs have been investing more time and effort developing and explaining them. Poor results coincide with poor explanations and rather improvised solutions in some cases. The same conclusion can be obtained

Table 2. Evaluation criteria for the teacher's assessment

Group	Skill	Mark	
Theory Comprehension	• Importance of the quality of the thermal union (vessel/dissipater).	0.5	**3.0**
	• Importance of the selected materials.	0.5	
	• Need of introducing as much dissipation area as possible.	1.0	
	• Idea of efficiency of a fin arrangement (thickness vs. separation).	1.0	
Practical Problems	• Explanation of the practical problems that they have found.	0.5	**0.5**
Employed Tools	• Direct or explicit references to the theory contained in textbooks.	1.0	**4.5**
	• Reported experimental measurements.	1.5	
	• Simplified analytical or numerical calculations or estimations.	2.0	
Innovation Search	• Proposition of original, risky and different solutions.	2.0	**2.0**

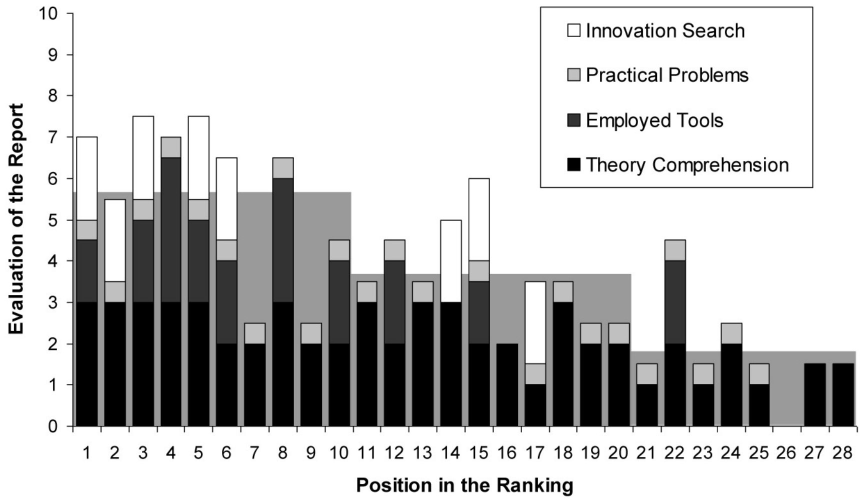


Fig. 3. Results of the teacher's assessment (Evaluation vs. Position).

if each of the four general evaluation skills that are described in Table 2 is analyzed separately in Fig. 3, using the labeled indications.

Some theoretical concepts were well understood and applied by the majority of the students while developing their designs. For example, almost everybody reported that they had included as much dissipation area as they could. Other interesting ideas arose among students, especially while they started to build their devices, with respect to the undesirable thermal resistance that is included if an optimal union between fins and vessel surface is not achieved. The concept of efficiency in a fin arrangement was not well understood by some groups, leading to some incorrect interpretations. For example, several groups pointed out that very thin fins are always desired not taking into account that this is only true when the number of fins is increased in conjunction. The practical totality of the groups pointed out the need of selecting a material with good thermal conductivity (aluminium or copper). Nevertheless, no group took into account the unsteady character of this phenomenon and its possible implications.

Only a third of the groups justified their design by means of mathematical or experimental approximations. This fact implies that the students trusted more in their own intuition or practical ability than in more abstract or complex analysis while developing their devices. Only three groups reported experimental observations or measurements. Eight groups handed in different approximate mathematical calculations or estimations, and three of them elaborated more with optimization tables in *Excel*. The groups that have executed and presented these studies have obtained better results, finishing in the upper half of the final ranking.

Almost everybody reported several problems when they were working with their own hands, especially related to the union between glass and fins, as can be seen in Fig. 4. These difficulties were overcome in most of cases by the students with the help of the teachers and the technicians who work in the laboratories and manufacturing area. Several groups changed all their conceptual design when they encountered inevitable practical restrictions.

Innovation has proved to be a valuable tool for obtaining better results. In fact, the first three groups presented quite original designs in contrast with more classical approaches, as shown in Fig. 5.

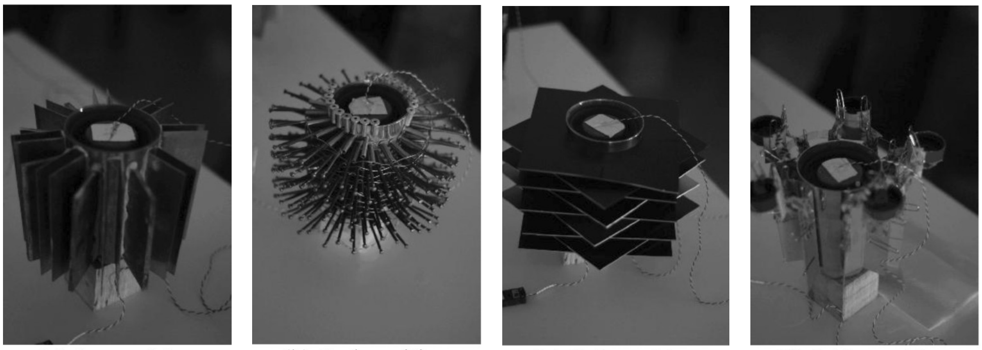
Fig. 4. Working on a device.

The first group (a) mechanized their fins giving them a 'U' shape and using a thick layer of copper. This increases and facilitates the union between the glass and the fins. The second group (b) surrounded the glass with a lot of hollow cylindrical fins made with aluminium (rivets) increasing exponentially the exposed area. Lastly, the third group (c) based their design on horizontally situated thick fins made of aluminium. A lot of groups discarded this approximation thinking that a vertical configuration is always better, which is not strictly true if the design is not optimized. A special mention is needed for group (d) that presented a refrigeration device with fins in direct contact with alcohol supplies to take advantage of the phase change phenomenon (this original idea was not explicitly forbidden in the rules). Although some practical design problems came up, they obtained an acceptable position in the middle of the ranking.

9. Student's assessment

The objective of the student's assessment is to reflect on the exercise based on some opinions obtained from the students. A few days after the contest, a questionnaire was handed out to the students in order to obtain their answers and the grading was between 1 and 5 (5 being a positive or affirmative answer and a 1 the contrary) to specific questions focused on the MACPE as shown in Table 3 and to collect general commentaries appended at the end. Applying some basic statistics the learning output and attitudes of the students toward the MACPE was assessed.

A number of 47 voluntary questionnaires were obtained from the students that had previously participated in the exercise. Assuming a Gaussian distribution in the answers to each question, representative mean values were obtained. The standard deviation for each set of data is around 1 (it ranges from 0.8 to 1.2) which is not large and therefore



(a) 1st position (b) 2nd position (c) 3rd position (d) 14th position

Fig. 5. Original devices and their position in the ranking.

Table 3. Statistical results from the student assessments

	Question	Average Value	Standard Deviation
1	Does this kind of exercise serve as a tool to motivate you to study the heat transfer course?	4.0	0.8
2	Does the exercise serve to assure the theoretical knowledge acquired during the course?	3.3	1.1
3	Does this sort of exercise help to spark interest for engineering issues?	4.2	0.7
4	Have some preconceived thermal concepts changed after solving this practical problem?	3.0	1.2
5	Have you been able to apply the theory to this practice?	3.4	1.0
6	Do you realize that in order to solve a heat transfer problem it is necessary to solve, not only theoretical issues, but also practical ones?	4.3	0.9
7	Has it been useful to encourage team work?	3.7	1.1
8	Have you realized the importance of the amount of fin area in contact with the water vessel?	4.2	0.8
9	Have you realized the importance of the quality in the joint between the fins and the vessel?	4.4	0.9
10	Was it too much work to carry out the exercise?	3.4	1.1

shows a fairly even opinion among the students. Several conclusions may be drawn from the student assessment results:

Questions one and three, related to the idea of a MACPE as something that engages the student in the course, received grades of 4 and 4.2 and therefore, students graded it very positively. However, question two, related to a MACPE as a tool to assure theoretical knowledge acquired during the course, obtained a 3.3, which means that students, even though they graded it positively, do not perceive it as the main output obtained from the exercise. Actually, some, but not many, of their theoretical concepts have changed due to the exercise: question four got a score of only 3. Even though they applied theory to the problem, it seems that was not the main student input according to the grading of question five which got a value of 3.4.

Students clearly see that the MACPE is very interesting in order to show that the real world is more than just theoretical concepts and that some practical problems also arise. This is the idea behind question seven which got a 4.3. In relation to the perception of the two important technical issues (questions eight and nine) in order to build a good heat sink device, they answered that after the contest this was very clear to them (a grade of 4.2 and 4.4). Finally, students graded with a 3.4 the workload of the exercise and therefore did not think it was too much work.

The normal way to study engineering is by taking notes and solving problems on paper. To apply the theory to something practical, something handmade, is to open the student to other types of work and it seems attractive for most of them. The following comments were collected from the questionnaires: 'It was a good motivation for taking a look at the lecture notes and to look for the key concepts behind a good design', and another one: 'The exercise provides a way to apply the theory to an experiment'. It can be observed that the exercise helps students go back to the lecture notes and reflect on how to apply the theoretical concepts to this exercise. Unlike the application of the theory of a typical problem solved on the blackboard, students like to apply the theory to an experiment. It is something different and it is a source of motivation.

The overall assessment was positive, and it may be concluded that it was an exercise that engaged the students, that helps the students relate the course with the real world and to have other kinds of learning experiences. However, it is not clear to what degree it helps them retain heat transfer theory. The student assessment findings are not intended to provide statistically significant results, but rather to assess and enrich the case study and hint at general trends.

10. Conclusions

A case study of a MACPE has been explained. The assessments from teachers' and students' points of view have been presented. It has been found that this kind of exercise helps students to be engaged with the course and to learn different things than those taught in the lectures. In particular, the exercise fosters aptitudes that engineers from industry want for the engineering students or future engineers.

The characteristics of the proposed problem have been especially chosen in order to analyze further learning levels or aspects: theory application to the resolution of a problem, practical issues from an engineering point of view, searching for further theoretical or practical information, learning to work in a team, innovation and use of imagination. Competing, playing and learning: solving a practical problem has been a close simulation of the real world.

The positive answer obtained from the students opens the door to foster MACPE type exercises in engineering courses with a high degree of application in order to be able to generalize the obtained conclusions and statistics. It has also been shown that the exercise is a fun and enriching experience for the student and clearly engages the students and makes them face the course with a better perspective.

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