

## Combining collaborative learning strategies in an energy engineering master course

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### ABSTRACT

Since 2010, many engineering Bachelors and Masters courses in the European Higher Education Area have been re-designed in terms of contents and methodology, among other reasons as consequence of the Bologna Declaration. From a visual aspect, blackboard-based teaching moved to projected transparencies and later on to computer-assisted presentations. Although the resources have changed, the global didactic approach has remained relatively similar. In many cases, the teacher still has a central standpoint in the teaching and learning process. Such an approach is perhaps not the best to face student weaknesses such as the lack of concentration, motivation and critical skills. In order to better face this problem, three different collaborative learning methods have been adopted in the master subject “Advanced solar thermal technologies” taught at the Universitat Politècnica de València (Spain).

The teaching methods which have been employed involve enquiry-based activities, business games and a solar cooker competition. This paper describes firstly the different active learning methods and secondly, it presents a discussion on the results of a survey which was answered by 23 out of the 29 students of the subject. The results indicate that students appreciate very positively the introduction of the three active-learning strategies.

In overall, the solar cooker competition has revealed to be the most effective of the three strategies with respect to the assimilation of concepts (83% agreement), to the exchange of opinions (87%), to the increase of learning (higher personal motivation, 78%), and the development of critical thinking (74%). Nevertheless, the business games or the enquiry-based activities also stand out individually for different reasons and in general, can be applied more easily in other subjects. For this reason, in a final stage, a methodology-planning is suggested for engineering studies, combining the benefits and limitations of each of the different teaching techniques.

*Keywords: collaborative active learning methodologies; business games; team work; group discussion; enquiry-based learning*

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### 1. Introduction

Many changes have been made recently in the European Higher Education Area [1], implying a re-design of the Bachelors and Master courses since the Bologna Declaration [2]. These changes have implied, at least in many Spanish universities, a shortening of the engineering studies (4 years for a Bachelor). Teaching in a Master to students coming from a Bachelor presents several

challenges since (i) it is difficult to maintain the students' concentration [3] during typical lectures of at least one-hour duration, (ii) they hardly have critical skills, which are essential in their future careers as engineers and (iii), their motivation is generally low. Productive motivation is nevertheless essential since it supports students' investment in deep learning and the development of professional competencies [4]. Recent studies have demonstrated both learning and motivational benefits from interdisciplinary education [5] and fully problem-based curricula [6]. A systematic integration of motivating strategies has proved to enhance engineering students' productive motivational perception for both course and careers [7].

In the previous 15 years, the teaching resources employed in the Universities have changed substantially. Teaching with blackboard has changed to computer-assisted presentations. The resources have changed, but the teacher remains as the central standpoint in the teaching and learning process.

The students now have plenty of resources available independently of the classes, and this has led, in more cases than we would like, to a higher student relaxation, a lower concentration and a more passive attitude in the classes. Stuart & Rutherford [3] studied the concentration of students and concluded that their concentration reaches a maximum after 10-15 minutes and then decreases sharply until the end of the class.

In order to face the lack of concentration, motivation and critical skills, three different collaborative learning methods have been adopted in the master subject "Advanced solar thermal technologies" taught at the Universitat Politècnica de València (Spain). Around 60-70% of the students come from the Bachelor of Energy Engineering and the remaining are mostly international students.

The teaching methods which have been employed involve enquiry-based activities, business games and a solar cooker competition. Business games are typically implemented as a practice strategy in entrepreneurial education [8], which is becoming more and more relevant in the design of engineering courses [9]. The process of enquiry is at the heart of active, self-directed learning [10] and is particularly interesting in heterogeneous groups with students coming from different countries [11]. Engineering competitions have proved to be a good opportunity for implementing project-based learning (PBL) based on real projects [12].

## 2. Methodology

### 2.1 Academic context

This work has been developed under the frame of the Master titled "Máster Universitario en Tecnologías Energéticas para el Desarrollo Sostenible" (MUTEDS), taught at the Universitat Politècnica de València (UPV). In particular, the subject for which the teaching methods are described is "Advanced solar thermal technologies". The latter is entirely taught in English at the Escuela Técnica Superior de Ingenieros Industriales (ETSII).

The mentioned Master is composed of 90 ECTS, among which 33 are mandatory, 27 optional and the remaining 30 ECTS are devoted to the Master Thesis.

The main aim of the master is to provide the necessary knowledge and competences in the field of energy. This involves a background on sustainable energy systems, efficiency, environmental impact, and analysis and optimization of energy systems.

The Master was initially designed for students with a previous background in the field of energy (bachelor "Grado de Ingeniería en la Energía or GIE). However, in the last 3 years approximately, among a total of around 30 students, only 10 come from GIE, 10 come from other degrees of UPV and the remaining 10 are international students. This implies that the starting point is totally different for the students, and very often, it is necessary to summarize basic concepts before presenting complex energy systems.

“Advanced solar thermal technologies” is an optional subject of the Master and has 4,5 ECTS. The subject is basically a description of different advanced solar systems (e.g. solar thermal power plants, solar cooling), and 4,5 ECTS is more than sufficient for this purpose. Thus, there is enough time, also resources and flexibility (30 students is a relatively small group) to design the subject in order to promote a deep learning and a better development of professional competences.

## 2.2 Objectives

The teaching activities have been designed starting from the following general weaknesses of the students:

- They can hardly maintain their attention in theoretical classes longer than 45 minutes.
- They don't have a capacity for critical analysis, which is nevertheless essential for their professional careers.
- Their motivation is generally low. Nevertheless, motivation has been proven to be essential for the development of soft skills and to promote a deep learning.

In order to face these weaknesses, different teaching techniques have been designed and adopted. The main idea is to avoid an excess of descriptive contents and theoretical classes, and to give a priority to the active participation of the students.

## 2.3 Educational activities

The previous weaknesses of the students have been faced by means of the following 3 group activities (Table 1):

- Enquiry-based activities
- Business game
- Solar cooker competition

Table 1 Teaching activities

Activity	Number of students per group	Frequency
Enquiry-based activities	3-6	Almost every class
Business game	5-6	3 2-hour classes
Solar cooker competition	4	Around 20-hour outside work and 2-hour in class work

The enquiry-based activities consist basically in open questions which have to be discussed by the 3-6 students of one row or a couple of rows of tables in the class. The students are given 1-3 minutes to discuss about the question and afterwards, one student of the class is selected randomly to provide their group answer, and the teacher finally discusses the answer. This approach is very useful, particularly in groups with many different nationalities, since the students can benefit from putting in common their different background and explanations on the subject. The students also describe the different questions “in their own language” and this helps them to achieve a deep learning.

The business game consists in presenting a real professional case, which is the design of a solar thermal power plant of 50 MW for a given location in Granada (Spain). In groups of 5-6, the students have to choose the technology they will employ (e.g. reflectors) and design the power plant using all of the material provided during the previous classes. Finally, they are asked to make a group presentation, which is their project offer, and the teacher acts as a potential investor, who has to decide which group proposal is most convincing for its quality.

The third activity which is presented is a solar cooker competition. Two four student groups had to design a solar cooker in order to manage, in real outdoor conditions, to cook an egg. The students had to present their design in an oral presentation, and they also participated in a competition during a practical lesson in which they cooked the eggs outdoors. The remaining students of the class chose other subjects and worked on specific topics (e.g. analysis of specific solar thermal power plant) which they presented as an oral presentation. The present work involves the analysis of only the solar cooker competition, which proved to be a better activity than the other oral presentations, since the practical work improved their motivation, their deep learning and their critical analysis. In total, the students dedicated approximately 20 hours on their own to design and build the solar cookers.

### 3. Results and discussion

#### 3.1 Survey 1.0

The following results are based on two different surveys carried out to analyze the impact of the mentioned teaching activities. A first survey (1.0) was carried out in order to know the level of satisfaction of the students with respect to each method. 23 out of the 29 students answered to both surveys (1.0 and 2.0). The second survey was conceived to detect more specific differences related to the strengths and weaknesses of each teaching activity.

How long can you remain concentrated in a master lecture	30 min	45 min	1 h	1h 30 min	2 h	Total
	4	43	26	17	9	100
I think it is necessary to break the monotony of a master class during a lesson of 2h	I totally disagree	I partially disagree	Neutral	I partially agree	I totally agree	
	0	0	4	22	74	100
Applying methods which break the class monotony increases my overall attention to the subject	I totally disagree	I partially disagree	Neutral	I partially agree	I totally agree	
	0	0	0	30	70	100
<b>This method has helped to</b>	<b>Enquiry-based activities</b>		<b>Business game</b>		<b>Solar cooker competition</b>	
Internalise the questions	75		73		77	
Better assimilate concepts	74		78		81	
Open my mind by hearing other students' opinions	78		78		83	
Increase my personal involvement due to the competition between groups	57		74		81	
Put myself in the place of a future engineer	67		79		76	
<b>OVERALL GRADE</b>	70		79		83	

Figure 1. Overall results of survey 1.0.

The three preliminary questions of the survey 1.0 refer to general matters, in order to know the concentration capacity of the students. According to Figure 1, 91% of the students state that they cannot maintain their attention during a 2-hour lecture. 96% of them agree that breaking the monotony of the classes increases their overall attention. The three teaching strategies of this paper aim to promote their personal involvement and increase both their attention and motivation. The results of survey 1.0 indicate that, in general, the satisfaction level was higher for the solar cooker competition, followed by the business game and finally by the enquiry-based activities. In particular, the business game was appreciated for putting the students in a real-life situation.

Despite the positive results of survey 1.0, the differences between the different categories of Figure 1 are small. For instance, when asked if a specific method helped to interiorize questions, the mean answer ranged from 75% (enquiry-based activities) up to 77% (solar cooker competition). In order to obtain more specific answers for each item, a more complete survey 2.0 was carried out.

### 3.2 Survey 2.0

In survey 2.0, the students were asked to answer if each teaching method was the best for each of the following aspects:

- Assimilate concepts
- Listen to the opinion of other students Deep learning due to a higher personal involvement
- Development of critical analysis skills

Table 2 shows the overall results of survey 2.0. The answers were classified as follows:

- 1: I totally disagree
- 2: I partially disagree
- 3: Neutral opinion
- 4: I partially agree
- 5: I totally agree

The survey 2.0 was carried out at the end of the semester, once the mark of each teaching activity had already been given. In questions 8 and 14 the students had to select their group number for the business game and solar cooker competition, which helped to correlate their answers. Although the answer options in Table 2 range from “I totally disagree” to “I totally agree”, in the specific case of questions 8 and 14, the students had to insert their group number in the business game or in the solar cooker competition. Instead of inserting the group numbers in Table 2, the authors have sorted the answers, so the first column (“I totally disagree”), only for questions 8 and 14, corresponds to the group with the worse grade and the last column (“I totally agree”) corresponds to the group with the highest grade.

Question	I totally disagree	I partially disagree	Neutral	I partially agree	I totally agree
1) I think I would have learnt more in other subjects if the same teaching methods had been applied	4	13	22	30	30
2) In overall, I think that the best would be to make me work, among all of the activities of the course, with all of the students and not with a limited number of students	0	43	22	30	4
3) ENQUIRY-BASED ACTIVITIES: I think that this method is the best to assimilate concepts	0	26	4	57	13
4) ENQUIRY-BASED ACTIVITIES: I think that this method is the best to listen to other students opinions	0	4	17	30	48
5) ENQUIRY-BASED ACTIVITIES: I think that this method is the best to learn more since I have more personal involvement	4	13	13	61	9
6) ENQUIRY-BASED ACTIVITIES: I think that this method is the best to develop critical skill	0	4	22	65	9
7) ENQUIRY-BASED ACTIVITIES: I think I would have learnt more if I had been in other groups	13	22	35	22	9
8) BUSINESS GAME: Select which was your group in the competition	26	26	13	17	17
9) BUSINESS GAME: I think I would have learnt more in another team	39	9	30	9	13
10) BUSINESS GAME: I think that this method is the best to assimilate concepts	9	9	22	39	22
11) BUSINESS GAME: I think that this method is the best to listen to other students opinions	4	13	26	30	26
12) BUSINESS GAME: I think that this method is the best to learn more since I have more personal involvement	9	9	17	39	26
13) BUSINESS GAME: I think that this method is the best to develop critical skills	4	4	22	57	13
14) SOLAR COOKER COMPETITION: Select which was your group in the competition	9	17	9	22	43
15) SOLAR COOKER COMPETITION: I think I would have learnt more in another team	26	13	35	13	13
16) SOLAR COOKER COMPETITION: I think that this method is the best to assimilate concepts	4	0	13	30	52
17) SOLAR COOKER COMPETITION: I think that this method is the best to listen to other students opinions	4	0	9	57	30
18) SOLAR COOKER COMPETITION: I think that this method is the best to learn more since I have more personal involvement	4	0	17	22	57
19) SOLAR COOKER COMPETITION: I think that this method is the best to develop critical skills	4	0	22	22	52

Table 2 Overall results of survey 2.0 (answers in %)

### 3.2.1 Strengths of enquiry-based activities

78% of the students agree that the enquiry-based activities are the best method to listen to other students' opinions. The second aspect which is most appreciated by the students in this activity (74%) is that it helps to develop their critical analysis skills.

Among the most relevant results of this methodology, as presented in Figure 2, there is a significant dispersion in the students' opinion, when asked if they would have learnt more if placed next to other students. Given that the students chose on their own where to sit in the classes, the group discussions were totally different in terms of the technical depth, depending on the students of each group. This happens particularly in groups including many international students, as is the case of the present subject. A possible improvement is to change randomly the student position in different classes.

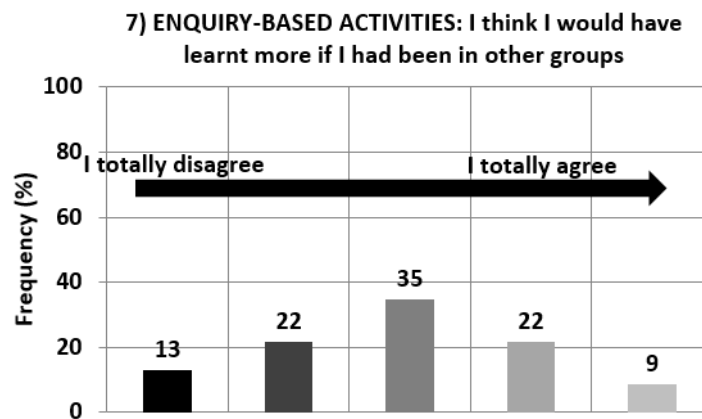


Figure 2. Impact of the group distribution in the learning process. Enquiry-based activities, survey 2.0

### 3.2.2 Strengths of the business game

The most relevant strength of the business game, as appreciated by the students, is that it helps to develop their critical analysis skills (70% of the students agree with this statement). The survey 1.0 also reflected another significant strength, which is that the business games places the students in a real-life situation. This aspect was not asked in survey 2.0 since it is only a specific question which cannot be asked, for instance, for the enquiry-based activities. In survey 2.0, the overall results of the business game seem to be very close to the results of the enquiry-based activities, but if the real-life scenario is considered, the overall satisfaction of the students is higher with the business game.

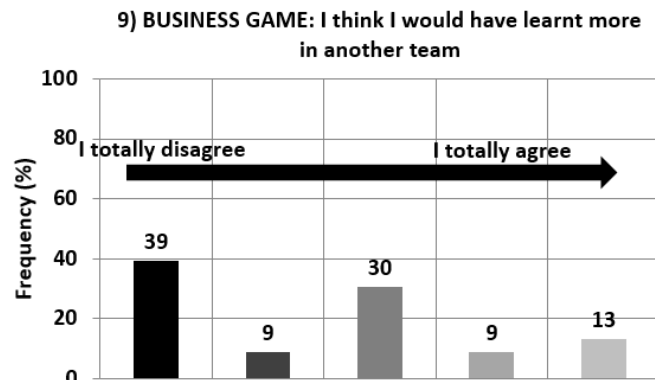


Figure 3. Impact of the group distribution in the learning process. Business game, survey 2.0

An interesting result of survey 2.0 is the dispersion in question 9 (Figure 3). The students were asked in this question if they thought that they would have learnt more in another group; 48% were not in agreement, 30% selected the neutral answer and 22% were in agreement. In overall, a significant part of the students had the impression that their team mates did not help to achieve a deeper learning. This fact highlights the importance of choosing correctly the groups, and if possible, in making them as homogenous as possible.

### 3.2.3 Strengths of the solar cooker competition

The solar cooker competition presented the best results for each of the assessed categories. In particular, the following values were obtained:

- Assimilation of concepts: 83%
- Listen to the opinion of other students: 87%
- Deeper learning due to a higher personal involvement: 78%
- Development of critical analysis skills: 74%

Among the different categories, the students most appreciated that the solar cooker competition helped to listen to the opinion of other students. The students appreciate that this activity is very practical, that it is a hands-on work where they apply concepts previously taught in the subject. Furthermore, as the design is totally open and hardly bounded by any restriction, this enhances their creativity, and a wide range of ideas are found if each member puts in common his suggestions.

In an open project such as this competition, discussing and sharing opinions is a very rich experience and this probably explains that 87% of the students thought that this methodology was the best to listen to other students' opinions.

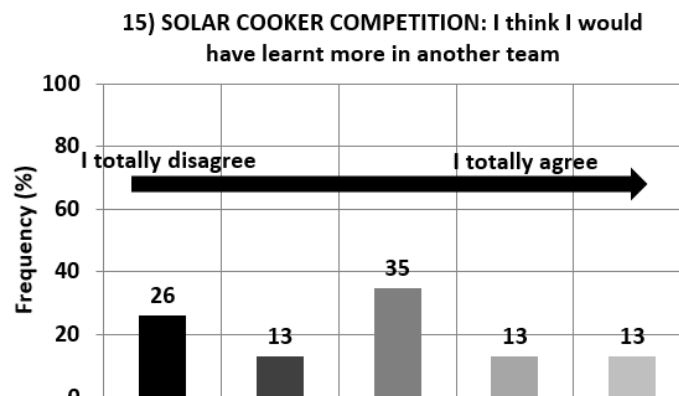


Figure 4. Impact of the group distribution in the learning process. Solar-cooker competition, survey 2.0



Finally, and as happened in the previous teaching activities, Figure 4 shows that there is a wide dispersion in the students' perception, when asked if they would have learnt more in other groups. This aspect is analysed in more detail in section 3.2.4.

### 3.2.4 Overall comparison of the three teaching methodologies

If each answer of the survey is given a linear weight from 1 (totally in disagreement) up to 5 (totally in agreement), the mean grade obtained for each teaching activity (survey 2.0) is:

- Business game: 3,63/5
- Enquiry-based activities: 3,78/5
- Solar cooker competition: 4,20/5

The previous numbers reveal that the solar cooker competition is clearly the best activity according to the students perception. The business game seems to be slightly below the enquiry-based activities, but as explained before, in survey 2.0 the students were not asked if they appreciated the real-life situation, and this is a significant strength of the business game. For this reason, it is not possible to draw a significant difference in the quality of the previous two methods, which in any case, should be complementary and not excluding techniques. The authors recommend enquiry-based activities as they are simple to integrate in any class, and the business game is very interesting, but should be integrated more seldom in specific situations.

The final written exam of the subject is where the students show, individually, their degree of knowledge and their developed skills. In the semester from 2015-2016 the mean grade was 7,1 and in 2016-2017 the mean grade increased up to 8,0. Although these numbers should be treated with caution (since the students are different every year), the results seem to indicate that the integration of the three activities has increased the knowledge and skills of the students.

Despite the overall positive results, the two surveys have shown several potential improvements:

- Given that the degree of learning in group activities seems to depend on the group distribution, it is important to organize several short activities at the beginning of the course in order to separate the students into several categories according to their group skills (e.g. leadership), or according to their previous studies (e.g. in the same University or abroad). This helps to mix them later and distribute the groups more homogenously. In fact, this strategy was introduced in the following 2017-2018 academic year and the overall satisfaction with respect to the group distribution was higher. In the enquiry-based activities, it is useful to change the sitting places of the students randomly in several classes.
- The solar cooker competition was very appreciated, not only by the 8 students who participated directly on it, but also by the rest of the class (100% of the remaining students), who asked to make this activity mandatory for every student. In the 2017-2018 academic year, this was actually done.

## 4. Conclusions

This study presents the results of three different teaching strategies which have been adopted in the subject "Advanced solar thermal technologies". They have been designed in order to face the

low student concentration in the classes, their low motivation, and to promote a deep learning by increasing their personal involvement.

The following main conclusions have been obtained by means of two surveys carried out in the 2016-2017 academic year. The surveys were answered by 23 out of the 29 students of the group.

- The enquiry-based activities stand out for helping to listen to other student opinions, and as a good methodology to develop critical analysis skills. For the instructor, they present the main advantage of being very flexible, since they can be adopted in any class, they do not require more than 3 minutes for each question, and they do not require any change in the teaching material or on its approach.
- The business games have as the two most relevant strengths the fact that they place the students in a real-life situation, and that they help to develop their critical analysis skills. Nevertheless, integrating a business game in a course is not so simple and it cannot be done so frequently as the enquiry-based activities. The authors recommend incorporating it only once or twice in a subject such as the presented one, of 4,5 ECTS.
- The solar cooker competition has provided the best results in each of the assessed aspects: assimilation of concepts, listening to other students opinions, deeper learning due to a higher personal involvement and development of critical skills. However, this is a very practical, hands-on project which cannot be applied in every course. If possible, the authors totally recommend such an activity, but are aware that the business games or enquiry-based activities are simpler to integrate in other courses.
- The results indicate that the degree of learning seems to depend on the composition of the different groups. Both the students and the teacher agree that the groups were not homogenous in terms of roles or previous academic background, and in this paper, several recommendations have been given to improve this aspect.
- Globally, the authors recommend introducing a hand-on project such as the solar cooker activity when possible, in subjects which can involve a design or construction activity. This sort of activities is generally very creative, the interaction between students is very rich and leads to a deep learning. Otherwise, the enquiry-based activities are also very interesting and can be applied in any class, while the business game can be wisely chosen for one or several classes regarding that the teacher can find a professional, real-life situation where the students can apply the concepts and skills developed in the subject.

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