INTRODUCING STATISTICAL EXPERIMENTAL DESIGNS TO CHEMICAL AND INDUSTRIAL ENGINEERING USING THE COLLABORATIVE AND PROBLEM BASED LEARNING APPROACH

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Abstract

This work describes the use of the Collaborative and Problem Based-Project Based Learning (PBL) methodology in a Statistical Experimental Design course for Chemical and Industrial Engineering students at the School of Industrial Engineering (ETSII) at the Technical University of Madrid (UPM). The objetives, motivation, and the roles of the teacher and the students in the classroom to get a better understanding of the concepts and examples are explained in detail.

Since 2000, there exists in our university (UPM) the aim to adapt the curricula to the European Education Framework agreed in Bolonia (1999). This implies modifications which influence among others the teaching methodology, with special emphasis in the self-learning, self-tutoring approach and teamwork.

We decided to introduce a Collaborative and PBL approach to convince and motivate the students on the usefulness of the subject they are learning, based in the essential role of real examples, problems and case studies. Besides, to create the students perception that statistics “tools” are an integrated whole rather than a collection of independent parts (closed-boxes) and it is really necessary in other disciplines. We consider these are the key points to the success.

The students work in groups of size three and the course is organized around seven tasks as follows:

Five main real problems, the analysis and peer review of one scientific article related with some items of the subject, and a project (their own experiment) the students are required to prepare and perform mainly in the laboratory of chemistry. At this point it is very important to remark the absolutely necessary collaboration of the teachers of the Chemistry Experimentation subject which provide students with solid technical and scientific training in chemistry.

At the end, the problems, the article peer review and the project cover all the course objectives, and allow the students to integrate newly adquired knowlegde with prior knowlegde and experiences.

Different places are used during the course: Each week, to present theoretical contents, the traditional classroom is used (one hour a week). The rest of the time, two hours a week, students work in one of the collaborative-cooperative classrooms available at School of Industrial Engineers at Polytechcnical University of Madrid.

An additional goal is evaluate the satisfaction of the students with the collaborative and PBL approach. The methodology for this evaluation is double: first, a qualitative study obtained from interviews with quality groups, integrated by the teacher and four students chosen by their classmates and volunteers and second, a quantitative study based on surveys among all the students to obtain a satisfaction indicator.

Keywords: Experimental Design, Statistics, Engineering, Collaborative approach, PBL.

1 INTRODUCTION

Statistical Experimental Design is nowadays a 9 credit subject in the first semester of the fourth year of the Industrial Engineer (oriented to Chemistry and Materials) and Chemical Engineer degrees at the School of Industrial Engineering (ETSII) at the Technical University of Madrid (UPM). The subject is taught 3 hours a week during 15 weeks (a semester).

As the second of the US Engineering Criteria 2000 explicity says an engineer must be able to " design and conduct experiments as well as to analyze and interpret data". So the subject we are presenting covers this requirement.

This work briefly depicts the use of the collaborative learning and PBL tools in the education process of this subject. The fundamental aspect of these techniques is that students learn by means of collaboration, they interchange information and work in groups in different tasks until all members have understood them. One of the main tasks carried out in this subject is the design, realization and analysis of a project, which includes the main points of the problem-project based learning approach: Relates theory and reality, increases student motivation and abilities to solve problems which connect different disciplines. All task are use both for learning and evaluation purposes.

The new methodology for teaching-learning, is oriented to the ECTS indicators. It implies the reduction in the theory lecture hours, and the increment of the autonomous –cooperative work done by the students and of the motivation activities.

In the current subject, the syllabus is:

- Random and mixed effects factorial designs
- Two level factorial designs
- Fractional factorial designs
- Robust design
- Evolutionary operation (EVOP) with two-level design
- Polynomial models
- Response surface methodology (RSM)

Previously to this subject, in the first or second semester of the second course, the students have studied Statistics, which includes, descriptive statistics, probability, inference, analysis of variance, factorial design with fixed effects and linear regression. One of the objectives of this matter is to provide the students the ability to communicate statistical information, so to speak statistical language.

They have also study previously a great amount of mathematics and computational methods. So it is important to take advantage of what the students known in areas which are relevant to applied statistics.

After the Experimental Design course, students much be able to translate statistical tools into practical applications. They should be provided by an integral statistics/chemical/technical knowledge, they understand general principles, interpret statistical results and transfer this interpretation to the engineering context.

2 METHODOLOGY

Statistical Design subject, as provides tools to make scientists to be able to solve problems, permits the collaboration with other engineering areas, and a practical orientation in the teaching-learning methodology.

Many authors have stressed the importance of the use of real or at least realistic problems of direct interest to students, and suggest the completion of a project [1,2,3].

In the case of chemical and industrial engineering (oriented to chemist and materials), these affirmations are even stronger.

Other authors remark the advantages of the cooperative work in small groups:[4], " ..students appear to learn better if they work cooperatively in small groups to solve problems and argue convincingly among conflicting ideas and methods".

We have decide joint together both approaches and organize the teaching-learning of the subject around seven task which require work in group to solve real problems and conduct an experiment in collaboration with other departments.

2.1 Tasks

As commented before, the students work in groups and the learning-teaching process is organised around seven tasks which cover all the topics of the course.

The time resolution for each task is around one or two weeks, depending on difficulty level, for instance one of them is a multiple choice test. During this time, a continuous assessment and feedback process is designed with each group to assist and guide the student learning. This is very important to know if the solution has been achieved by consensus and to evaluate what is the work of students as individuals and as a team member.

The first task is a multiple choice test which evaluates previous knowledge on statistical topics. Four task involving the analysis of real problems related to the subsequent topics of the syllabus. It must be pointed out that although the teaching program has remained almost statics as well as the practical orientation of the course, the real examples selected have been changing over time. This imply a extra work load for the teacher, because every year different tasks must be prepared and evaluated.

As commented befor,there is a general consensus of the great importance of real examples or realistic in order to convince students of the value of statistical experimental design and analysis in their future.

Finally two different tasks are proposed: the analysis of an scientific article and the completion of a project. We go more in depth on these two tasks.

2.1.1 Peer review of an article

Every year, the teacher select several articles to be analysed by the students. The articles are related to one of the topics of the course. The selected articles are changed every year to avoid the use of previous works to carried out the own work. Some examples of the selected articles are in references [5,6,7,8].

Each group decides the article which want to review. The review process includes the evaluation of the objectives, of the methodology, the independent analysis of results, the proposal of alternatives to the analysis, the formulation of their own conclusions and the comparison with those of the authors of the article. Usually 20 groups are formed, so as different groups analysed the same article, we reserve some hours of the schedule to promote discussion between groups.

2.1.2 Project

With the project the students take full advantage of statistical techniques, not only for analyzing experimental results, but also and principally, first of all, for systematically and carefully planning the experiments to obtain unbiased and valid conclusions: a good designed experiment must yield exactly, the type of information we are seeking. If our investigation is based on a badly designed experiment, the results and conclusions are unreliable. A majority of projects involve two level factorial design or a fractional factorial design. Project includes the problem definition, identify the response variable and the design factors, select the matrix design, conduct the experiment, analyse results and formulate conclusions in statistical and technical languages.

The projects can be classified in three categories:

- Collaborative projects, perfomed with the collaboration/supervision of teachers of other subjects. At present we collaborate with instructors of Chemical Experimentation, Inorganic Chemistry and Industrial Chemistry. Also, although in lesser extend, we collaborate with the teachers of the Laboratory of Materials. These are the most interesting.
- Chemist, Physics or Mechanics projects, simpler than previous, which are carried our at home.
- Projects on a general basis, related to students' everyday life.

The project imposes an extra work load on students and is very time and resource consuming. Students prepare a written report and a multimedia presentation as result of their own experimental design, because sometimes one member (randomly selected) of each group, is required to give a presentation of the work providing an additional assessment criteria.

2.2 Evaluation

In the subject evaluation we have decided to take into account a global exam, the tasks and the project. The weights have changed over time due to some features: we have realized that sometimes, students do really well the tasks and the project, but they fail and make naive errors in the exam and on the contrary.

Besides all task and project mainly reflects the work of the group, and although the team leader changes every task, and all members of group have a very active attitude, the individual knowledge must be erroneously evaluated. Therefore, we have impossed an exam which provides and additional input for the individual knowledge.

The student's final grades are then the joint result of:

- The grade of the global written exam of the subject, with a weight of 50%.
- The grades for the main problems, and peer review of the scientific article, which reflect the student's skills on case study analysis. This grade has a weigth of 25%.
- The grade of the project (their own experiment). This grade has a weight of 25%.

3 COURSE ORGANIZATION. IMPLEMENTATION

The course is organized around the main seven topics described in section 1. Each item covers about two weeks and it is mainly focussed in understanding concepts and ideas introducing mathematical formulas when necessary and putting special emphasis on the real problems which can be solved with the specific topic.

The subject is though three hours a week. For each topic the first part last from one to three hours and takes place in a traditional classroom. It consists of the explanation by the teacher of the main concepts of the educational unit using a real or realistic problem from the areas of the students interest and intensification (materials, chemistry).The rest of time assigned to the topic, students work in one of the cooperative classrooms available at our School. The class contains round tables with three computers and nine positions. The ratio student-computer is three, or each team (formed by three students) has a computer. Cooperative class can be occupied by 72 students.

During the last five years, we have experienced an increase in the number of students from 30 to 60 nowadays**.** The student – to teacher ratio is 60 to 1. We think that the optimum student to teacher ratio is lower that the one we have. The optimum, in our opinion, should be 45. A lower rate allows a more student contact, more participation with an increase motivation towards the subject.

Lab sessions have two parts: Firstly, the students reproduce some examples given in the traditional room, after that, a problem with similar difficulty is introduced by the teacher, and within the groups, students study the concepts and discuss the problem. At the end of some sessions, each team prepare a written report, which includes results and conclusions of the problem analysed. Finally the task corresponding to the specific topic or topics is presented and the objectives and schedule are clarified.

Tthere are many statistical packages that provide similar techniques in the lab sessions, our students work with StatGraphics and MatLab, because of availability, simplicity and graphical orientation. Now we are evaluating the use of R.

4 OUR EXPERIENCE

We are working with these methodology since 2005 (five semesters) and we have perceived a positive change in the student attitude. Some problems arisen implementing the approach have been solved taking into account the student input. As the matter is in the fourth year, the students have experience of working on groups, nevertheless some conflict could arise when has not carried out the assigned task. That is why there are some minor changes in group compositions in the first two weeks.

Aspects of the course, difficulties with the matter, problems arisen implementing the approach, and different questions are treated directly with the groups and through the Quality Groups. We have use this organization previously in other subjects and it is really useful. The purpose is not hot evaluate the teacher (there are other mechanisms to accomplish with) but to work together students and teacher to improve the quality of teaching-learning process. Detailed explanation of the group composition and working methodology is explained elsewhere [9]. Besides an quantitative analysis is performed from the surveys that the students complete at the end of the year. The survey includes different items of the subject, different attributes. With the results a satisfaction indicator is constructed which identifies "main" attributes to be focussed on. The results are really satisfactory.

With this methology, students promote the interaction with teacher, are more active and are really involved in the proposed activities. The class attendance is most of days around the 90%-100%.

In the course different alternatives are used for the different topics: traditional class, cooperative learning, work in groups, collaborative work with other departments, written test, lab session, oral presentation of results, written reports….In our opinion, these benefits student motivation.

The environment of collaboration with other departments is really important: Diffusion of results, availability of relevant cases studies……

Every year, the projects performed by the students are incorporated in real –examples data base [10, 11], which provides an extra source of information and teaching material with real-experiments to be used in next years. In any case, the work load of the teacher is important, due to the continuous educational effort in preparing the course materials and evaluating the tasks. .

In the last years the number of students has increased until 60, so 20 groups are organized. It is difficult to provide experimentation support for the project for all of them. We are now evaluating the possibility of virtual experiments, using software environments which reproduce real situations of interest as proposed in [12]. This idea seems to us really interesting, because we have experience in the simulation of stochastic process oriented to teaching-learning process.[13,14,15]

5 CONCLUSIONS

The collaborative–problem based approach has been proved very useful and motivating in the teaching-learning process of the Statistical Experimental Design course for Chemical and Industrial Engineering students at the School of Industrial Engineering (ETSII) at the Technical University of Madrid (UPM).

The different tasks, the study of real cases, the article peer review and the project cover all the course objectives, and allow the students to integrate statistics and technological knowlegdes, and what is more important, to provide a basis for the ongoing learning.

The collaboration with other departments and the work in group have influenced positively student interest and attitude.

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