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'Applied Scientific Method' in the Laboratory*

BEATRIZ AMANTE,[1] MARIA MARTINEZ-MARTINEZ,[2] ANA CADENATO,[2] ISABEL GALLEGO[3] and NURIA SALAN[1]

[1] The Universitat Politècnica de Catalunya BARCELONATECH, School of Industrial and Aeronautic Engineering (ETSEIAT-UPC), Spain. E-mail: beatriz.amante@upc.edu, nuria.salan@upc.edu
[2] The Universitat Politècnica de Catalunya BARCELONATECH, School of Industrial Engineering (ETSEIB-UPC), Spain. E-mail: rosario.martinez@upc.edu, cadenato@mmt.upc.edu
[3] The Universitat Politècnica de Catalunya BARCELONATECH, School of Industrial Engineering (EPSC-UPC), Spain. E-mail: isabel@ac.upc.edu

This paper provides a description of how to incorporate and develop a specific set of applied skills for university science and technology laboratory activities. These skills are what constitute the Applied Scientific Method for problem solving at this field. The application of this method aims to enhance the student learning process in educational laboratory environments. With the objective of facilitating the understanding of these skills, a series of components and elements were outlined. Subsequently, to allow for the systematic integration of each of these components of the Applied Scientific Method throughout the course, four different levels of complexity were established. Three key stages of the learning and skill development process were then incorporated based on the various lab activities carried out; pre-laboratory, in-laboratory and post laboratory. The Applied Scientific Method was applied to the laboratory components of three courses of the Chemical and Industrial Engineering degrees of the UPC-BARCELONATECH (Spain). The first results obtained show a positive reception (pre-lab, in-lab and post-lab) by the student body and, moreover, demonstrate higher standards in the projects presented as post-laboratory assignments.

Keywords: skills; laboratory; scientific method; engineering; science and technology

1. Introduction

Increasingly more authors are beginning to agree on the fact that there is a lack of synergy between science and technology laboratory activities and the specific academic subjects to which they correspond, plus the fact that the ineffectiveness of poorly orchestrated laboratory activities on self study is becoming increasingly evident [1–2]. This apparent contradiction could be explained by various factors; the most notable of which being the fact that the learning objectives and learning outcomes of laboratory assignments are generally deficient in clarity.

The use of conventional laboratory methodologies doesn't always provide the most appropriate tools for students preparing for the professional world. For this reason the absence of the 'Applied Scientific Method' in laboratory assignments, could lead to students being deprived of key elements of applied professional training.

The main limitations of conventional laboratory sessions have been observed to include:

- Lack of student involvement in the design of experiments: This activity typically implies the student having to group the necessary assignment materials via the use of a list of 'step by step' instructions, which in turn, provides the basis for developing a procedure and reaching a determined outcome; (either be data or a physical product). Under this 'traditional' methodology the idea that is transmitted to students is that the sole objective of the assignment is the efficient execution of the instruction manual; which is to be demonstrated by obtaining a desired result. Furthermore, the student will only get a good assessment or evaluation score if the experiment results are 'correct.'
- Time limitations for experience development, often leave students with the option of only 'doing' as opposed to having the liberty of devoting their time to 'learning'. This feeling is compounded when laboratory use is a peripheral part of a subject, in which the objective is simply to carry out practical tests of theories or to give instruction on the use of laboratory equipment.

Any application of alternatives to minimize these limitations and increase the effectiveness of self study in laboratories, will require significant changes in methodology, such as pre-laboratory planning [3–4], that are essential for the proper development of the overall experiment or activity. Furthermore, a clear specification of the learning objectives based on the expected results of the laboratory activity will need to be carried out [5–6]. An additional motivating element would be to divide the experiment or assignment into various short steps, so that students could take on the role of

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researcher and thus assume the responsibility of their own results. Such a practice would encourage students to incorporate skills gradually and consistently whilst at the same time taking into account the vital part that the post-laboratory tasks [4, 7–8] play in the overall activity.

The aim of this paper is to demonstrate that, by incorporating the 'Applied Scientific Method' for problem solving into the laboratory activities of three subjects of different engineering courses of The UPC-BarcelonaTECH (Universitat Politécnica de Catalunya, Spain), there was a higher level of motivation and involvement of the students. Based on this we could deduce that the overall positive effects of this method on the students' learning process were quite significant.

2. Teaching and learning objectives

The targets of this experiment were:

- To define which skills are to be integrated to solve problems in the laboratory and to explain the *Applied Scientific Method* in the Laboratory (ASM) as a practical tool for problem solving in science and technology laboratories.
- To establish levels of proficiency that will allow for the introduction and progressive development of ASM while covering all the laboratory activities of diverse subjects.
- To define possible criteria and ASM assessment tools, by means of adapting activities so as to facilitate the implementation this method in three subjects and by evaluating the outcome of the experience through student satisfaction surveys and teacher feedback.

3. Methodology followed

Firstly, to more effectively explain the concepts of ASM, we have grouped all of the essential laboratory skills required for professional applications into a series of components. Moreover, as an additional means of furthering skill acquirement in a particular area or subject, different levels of complexity were defined for each component.

As part of the skill acquirement process, a design and activities assessment was also included; with the process being rounded off with the results of the alignment of three subjects of science and technology laboratories of UPC-Barcelona TECH. The evaluation of the experience of each student was based on student satisfaction/ opinion questionnaires.

3.1 Definition of the practical skill required for the application of ASM

Skill acquirement through the ASM combines knowledge, skills and approaches that allow students to achieve a satisfactory outcome for a given situation [9].

To further the process of understanding, integration, development and skill evaluation, a specific set of components and elements were defined as outlined in Table 1.

In order for a component to be defined, it is not necessary for all elements to be present at any one time; nor do they have to be in the same order or level as shown in Table 1 and Fig. 1. For this

Table 1. The Components and elements that comprise the practical skill ASM

Components	Elements
Measure/Acquire	Experimental data acquirement. Systematic and reliable data register and documentation. Correct expression of data and results. Use of pre-calibrated tools or instruments needed to perform experiments.
Experience	Posing and testing hypotheses. Application of instrumental techniques or basic laboratory operations. Planning, design and experimentation or execution of scientific and technology research. Correct data management, representation and analysis. Evaluation of the validity of the results.
Model	Proposal and choice of mathematical models to explain experimental results. Calculation or estimation of the model parameters chosen and optimization of data. Establishment of model limits through analysis and debate of their validity. Validation of proposed models through observation and experimentation.
Project/Forecast	Utilization of the resulting models to make predictions, simulations and calculations based on the requirements of the project or practical assignment in question. Building of confidence and establishing hypotheses. Improvement of the experiment or research implementation. Justification of results and drawing of conclusions.
Decide	Risk-taking based on confidence in the validity of the model and predictions. Decision-making based on previous findings and feasibility (technical, economical, etc.) proposals. Communication, explanation and justification of conclusions and decisions.

purpose a grading system of the various components based on the number and levels can be considered.

3.2 Component levels

Firstly, we established different skill levels necessary for acquiring the components which make up the ASM. These proficiency levels constitute a framework which, when defined in conjunction with the academic curriculum of each student, provide us with a means by which we can progressively integrate the elements of each component, which will be revealed in every stage of a relevant degree or course.

Four levels for each component; graded in terms of complexity from lowest to highest, were identified as measuring tools to be used by teachers. Their application also encompasses their use as guidelines for the development of instruments that facilitate the assessment on an individual level, inter-student level or from staff to student. One must bear in mind that not all activities of a subject should be seen on the same level, as a subject may very well require work at different levels, depending on the component in question. Fig. 1 shows different levels of two of the components; 'Measure/Acquire' and 'Decide'. The remaining components can be found in the complete guide [9] of the ASM.

3.3 Skill integration

This step, once the 'scientific method' has been defined, comprises the highlighting of those activities capable of ensuring the acquisition of the generic and special skills which constitute the ASM, in a progressive and coherent manner.

The choice of activities will be scheduled in a way

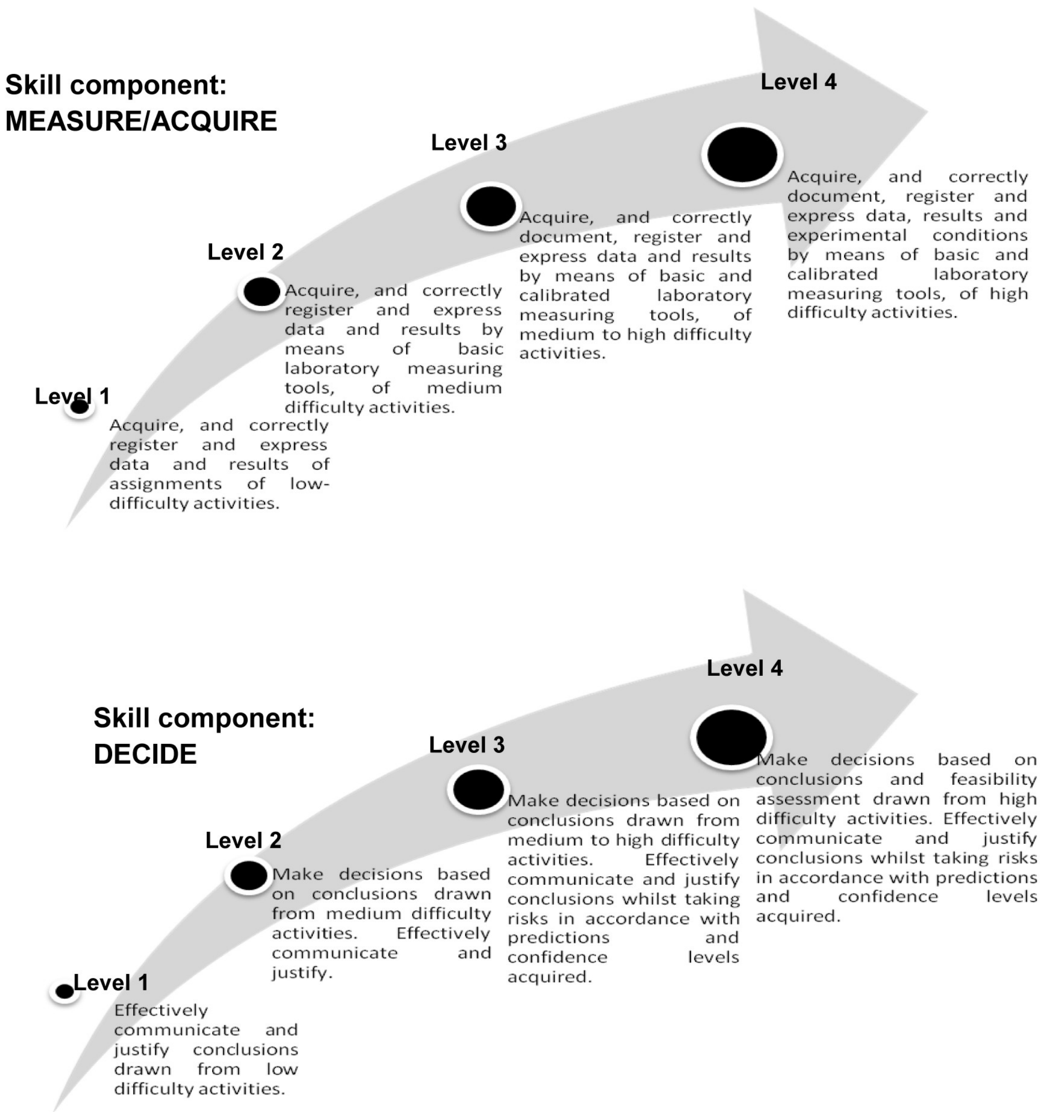


Fig. 1. Skill levels for two specified components of the skill.

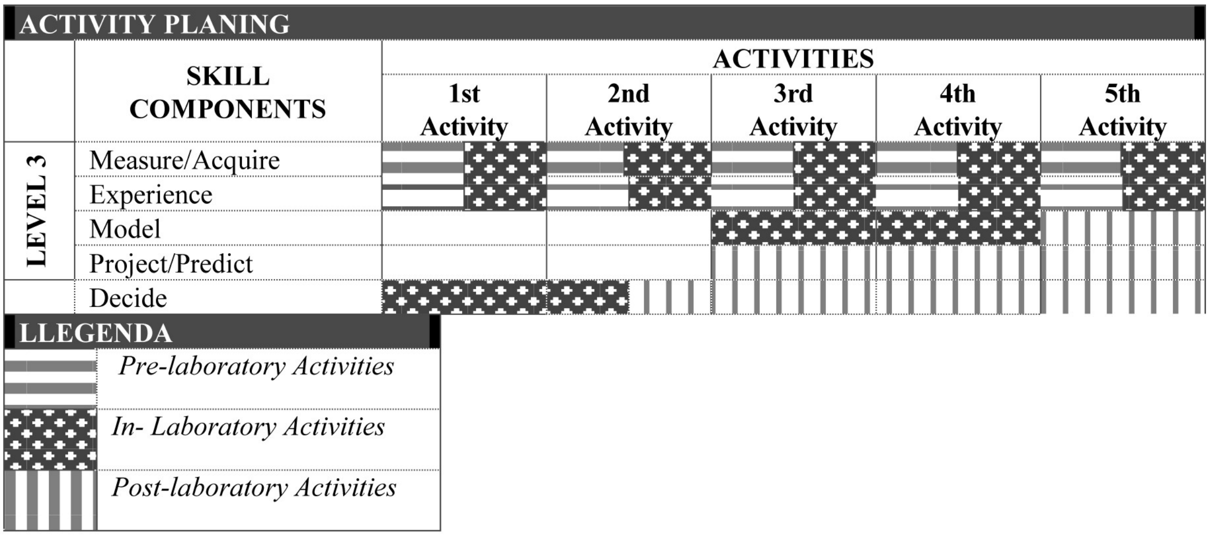


Fig. 2. Example of an activities planning chart for the introduction of ASM at level 3.

that enhances skill acquisition whilst integrating the process of self study. It is desirable that such activities be distributed throughout the self study process, thus allowing for an increasing degree of difficulty; starting from the next lowest level and continuing on towards the acquisition of the specific skill, as defined in the ASM. This trend is to continue until the expected results of the respective proficiency level have been achieved. Fig. 2 shows an example of an activities-planning class in which the skill components of level 3 are developed.

In the following sections**,** we will introduce an example of an activity designed to integrate this practical skill in specific subjects of varying complexity level.

3.4 Activity design form for specific skill development

Creating an activity involves the identification and establishment of teaching objectives and learning outcomes, teaching methodologies and the definition of a system of evaluation. The items described

GENERAL ACTIVITY INFORMATION	
FIELD OF KNOWLEDGE:	
SKILL LEVEL:	**SKILL COMPONENT**:
ACTIVITY Number:	**ACTIVITY IDENTIFICATION**:
TIME DEVOTED TO ACTIVITY Pre-laboratory: _____ h. In lab: _____ h. Post -laboratory: _____ h.	
ACTIVITY DEVELOPMENT	
SUBJECT CONTENT TO BE APPLIED TO ACTIVITY	
OBJECTIVES AND LEARNING OUTCOMES Must be consistent with the objectives and learning outcomes established as well as the level to which the activity corresponds	
Objectives and learning outcomes inherent in the activity Objectives and learning outcomes of skills (according to level of competence)	
ACTIVITY METHODOLOGY This section describes the pre-lab, in-lab and post-lab activities that will allow students to develop skills whilst considering their coherency with established objectives, learning outcomes and how they relate to the level in question.	
EVALUATION: STRATEGIES, TOOLS CRITERIA AND GRADING The development of this section must be consistent with the objectives and learning outcomes in addition to the ASM level and methodology defined in this form. Grading must take into account the time students need to invest in the activity, their individual contribution to the learning process (in relation to other subject activities) and the weight that these factors will carry when it comes to the final evaluation grade.	

Fig. 3. Generic activity form layout.

Table 2. The most significant deliverables for specific skill acquisition

Questionnaires	Raised by teachers and handed in by students in written form.
Oral questions	Raised by students or teachers.
Development tests	Open ended questions that have been debated and responded correctly within a certain time frame.
Reports	Any written material derived from experience in the laboratory.
Performance recording	Documentation compiled by the teacher based on any action carried out by students in the lab.
Laboratory notebook	Collection of observations, procedures and data obtained during experimentation.
Practical assignments	Situations raised by the teacher in which most of the components of a specific skill have to be put into practice experimentally.
Oral presentations	Structured exposition geared towards teacher and colleagues.
Poster presentations	Written statement in poster format, and presented to students and teacher.
Student portfolio	Collection of evidence of the learning process along with the personal reflections of the individual or collective reflections of the group.
Projects	Assignments carried out in a closer and more realistic manner to the situation posed, thus providing more flexibility for the students' development. Such projects are inclusive and are usually performed in group settings.

are listed in Fig. 3, which shows a sample of the activity sheet which students must be provided with from the onset, along with other relevant materials.

It is a requirement for the overall planning of the various student activities to be made publicly available prior to the commencement of the training period. This is especially relevant for those activities which provide sound evidence of the growth of the learning process [10] as well as the incorporation of an improvement plan in which faculty members can submit their own ratings and input on the development of the activity. Such a procedure will therefore allow students to progress in their learning throughout the training period.

This paper presents the ASM as applied to three UPC-Barcelona TECH laboratory subjects of different skill levels: Experimentation in Chemistry II (EQ II, level 2), Experimentation in Chemical Engineering (EEQ I, level 3), and Projects (P, level 4) of the degrees in Chemical Engineering and Industrial Engineering.

The methodology can be described as follows:

- A detailed presentation of custom-made activities, using the appropriate form.
- The direct relationship between each of the components and elements that integrate the ASM and are developed during the different stages (pre, in and post-lab).
- Finally, we present the results of the ASM in order to verify that this methodology provides special training which improves students' learning process.

3.5 Deliverables and ASM outputs

It is essential to identify and obtain evidence which can enable teachers to assess and verify progress (or lack thereof) throughout the course and various activities, as well as the degree in which the special skills have been acquired. The most significant of which are those shown in Table 2.

EVIDENCES	COMPONENTS					LAB STAGES		
	Measure	Experience	Model	Project	Decide	Pre-lab	In-Lab	Post -lab
Questionnaires	X				X	X	X	X
Oral questions	X	X	X	X	X	X	X	X
Development tests		X		X			X	X
Reports	X	X		X	X	X	X	X
Performance recording	X	X					X	
Laboratory notebook	X	X				X	X	
Practice tests	X	X	X	X	X		X	X
Oral Presentations					X			X
Poster Presentations				X	X			X
Student Portfolio	X	X	X	X	X	X	X	X
Projects			X	X	X		X	X

Fig. 4. List of deliverables related to the components and the three stages of laboratory activity.

Figure 4, related to the components of the ASM and laboratory time, summarize the key points required for the assessment of the ASM in science and technology laboratory assignments.

By assessment tools we refer to those support tools that facilitate the collection of information from applicable deliverables and, in addition, are relevant for the analysis of the degree of skill acquired by the students (the use of different formats at different points of the training process is desirable).

It is worth mentioning that the most significant instruments used to compile information on student competence in science and technology laboratories, are questionnaires, records, student portfolios etc. as shown in Fig. 4.

4. Example of an activity

At this point we post a detailed example of an activity of the EEQ I subject, and a description of

GENERAL ACTIVITY DATA		
SUBJECT/COURSE: Experimentation in Chemical Engineering I (EEQ I)		
SKILL LEVEL: 3	**SKILL COMPONENTS INVOLVED**: All	
ACTIVITY NUMBER: 1	**TITLE**: Measurement and modeling of vapor-liquid equilibrium of binary systems	
TIME DEVOTED TO ACTIVITY		
Pre-lab: 4 h	In-lab: 6 h	Post lab: 20 h
ACTIVITY DEVELOPMENT		
OBJECTIVES AND LEARNING OUTCOMES		
After the activity, the student must be able to: 1. Measure liquid phase, vapor phase and boiling point composition. 2. Construct a vapor-liquid equilibrium diagram at constant pressure. 3. Compare experimental results with those provided by a theoretical model such as Van Laar, after having previously calculated the activity coefficients of each component. 4. Use an Abbe refractometer as an analytical tool for determining the composition of a two component liquid mixture. 5. Use the obtained equation and deducing results in different experimental conditions. 6. Evaluate decisions using data obtained		
METODOLOGY		
In order to stimulate motivation, students must be made aware that the experiments performed are based on the real industrial world. Likewise it is important to relate experimental results with examples discussed in the laboratory or classroom sessions. Activities are divided into three steps: • Pre-lab: Consists of tests and questions carried out previously that are related to the experiment and the specific concepts that are to be addressed and finally submitted in a report format. • In lab: Consists of the development, in groups of two, of experimental activities • Post lab: Consists of data acquisition interpretation, hypothesis testing, drawing conclusions and making decisions.		

Fig. 5. Activity form designed to develop the ASM.

the process followed for development and implementation (Fig. 5).

In Fig. 5 one can observe in detail, the data corresponding to the objectives, outcomes and methodology, in addition to the general information about the activity. This information underlines the EEQ I subject, the number and title of the activity, the skill level and also the hours of time devoted to the activity by the students.

Teachers should design and plan a range of such activities in order to develop and monitor the ASM throughout the learning process. On the other hand, the teacher should design a skill assessment scheme which provides evidence of learning outcomes during the training process of each student [11]. The feedback from these assessment tools allows the students to see at what stage of the training process they are at any given moment [12].

4.1 Pre-lab tasks

As a means of assessment, prior to beginning any lab work, a brief teacher-student meeting consisting of an oral question and answer period, could be held with the purpose of testing the degree at which students understand the experiment. During this session, students could present a pre-lab report which will serve mainly to help both students and teachers alike to plan activities. This will, as a result, enhance the learning process both through the identification of issues related with the lab session content as well as the visualization of the plan outline.

Figure 6 shows the preliminary report required of the students prior the experimental activity explained above entitled 'Vapor-liquid equilibrium of binary systems measurement and modeling'. Issues related to the skill components can be shown through the different sections of the experiment, allowing for the self evaluation of the student while in turn assisting the teacher in their own assessment tasks.

4.2 In-Lab tasks

During the laboratory session students are required to carry out tasks based on the plans and designs established in previous assignments. Furthermore, during the experimental session, the evaluation of the work will be carried out by the teacher by way of the direct monitoring of the obtaining and registration of experimental data, and experience implementation (procedures and observations will also be reflected in the lab log book). At the end of the session, a lab report must be submitted complete with calculations, results and discussions. During the following session the teacher will return the report, once it has been corrected, plus any relevant additional feedback.

At the end of the process, the information col-

Measure/ Acquire	
To what level of precision must measurements be carried out in the experiment?	*It depends on the accuracy of the volumetric instruments used during the different phases of the experiment procedures.*
What are the benchmarks for these measurements? *Is it necessary to carrry out control tests?*	• Tabulated standards based on experimental results. • Yes, a calibration curve will be produced using a refractometer
To how many decimal places should the numbers used in calculations be rounded off?	*Calulation results should be rounded off to the same number of decimal places depending on the nature of the data obtained,*
Experiment	
What will be the control variables and response variables of the system that is to be analysed? *Which system variables must be set at a fixed level in order to simplify the experiment?*	• Control variables: temperature and composition • The pressure within the lab
Decisions: Degree of variation of the control variables?Why? Name of measurements? Why?	*From x=0 to x=1*
Model	
Which model should be used for correlating control variable data with response variable data?	*Identify the possible equations that relate temperature with composition and decide which is the most adequate.*
Is the selected model empirical or is it based on fundamental principals? *What is the range of accuracy of the model?* *Can the model be used for extrapolation or only for interpolation?*	*Empirical* *From x=0 to x=1* *For interpolation only*
Is it necessary to try out different models? *Is it necessary for these modes to be validated?* *What should the decision to use one model or the other be based on?*	*Van Laar or Margules* *Yes* *The model that best explains the experimental data.*

Fig. 6. Pre-lab questionnaire for the EEQ I subject.

lected during the lab session should be used to develop the final document to be submitted; the post-lab report. This document, after repeated exercises with varying degrees of difficulty, provides a design solution to the problem or need raised by 'the client'. Students are to type the report, draw conclusions and make decisions in the same manner as professional technicians.

4.3 Post-lab tasks

The post-lab step allows the student to argue and draw conclusions surrounding the activity at hand while at the same time extrapolating into real situations of the professional world. Other key components include the documentation of the extent at which possible lessons are learned as well as the identification of strengths and weaknesses. In Fig. 7 we can see the report designed for this stage in the EEQ I subject. It is clear that a project is essential in the post-laboratory stage in order to introduce the last component of the specific skill: decide

During the assessment procedure codes were used which provided objectivity in the corrections carried out by all professors whilst allowing the students to know in advance what was required of them.

Table 3. Per cent weight of importance of the post laboratory activities for each subject

Subject	Percentage score out of 10
EQ II	20
EEQ I	25
P	60

The grading method used in the three subjects comprises a 10 point system. As you can see in Table 3 according to the subject in question, a percentage score is given with the aim of reflecting the level of student commitment to the task or project carried out in the laboratory. One can observe that in the initial levels of this skill, the overall percentage of the subject is lower but in level 4 of the last year this percentage reaches a 60% score out of an overall possible grade of 10.

5. Main results

In order to evaluate the way in which the ASM was received by the students, we carried out a survey to evaluate the level of satisfaction of all participants. In Table 4 we can see the average results of eight of the questions surrounding the three subjects (Experimentation in Chemistry II (EQ II) and Experimentation in Chemical Engineering I (EEQ I) of the degrees in Chemical Engineering and Projects (P) in Industrial Engineering. It is worth pointing out that the level of complexity increases from subjects EQ II to P. The student number for both of the first subjects was 25, whilst for the Projects subject, it was 60. The levels of satisfaction vary between 5 and 1 (5 meaning in strong agreement).

MEASURE/ACQUIRE		
Experimental data acquisition procedure	Experimental procedure	In-Lab
Results and condition recording and documentation	Experimental conditions and calculation results: table with experimental data	In-Lab
Correctly expressed data and results	Temperature (ºC)	In-Lab
Measuring instrument selection for appropriate practical application	Equipment and instrumentation for experimental procedure	In-Lab
EXPERIENCE		
Equipment and instruments for experimental procedures	Experimental procedure	In-Lab
Planning design and performance of experiments	Planning/design and execute experiments	Pre Lab
Correct management of experimental data	Results and calculation	Post Lab
Correct graph plots and interpretation	Results and calculations	Post Lab
MODEL		
Mathematical models selection (analytical and numerical) for adequate description of experimental results	Regression curve of the refractive index - mole fraction Van Laar o Margules Discussion of results	Post Lab
Establishing model limits through verification and discussion (extrapolation and interpolation)	Discussion of results	Post Lab
Validation of proposed models through and observation and experimentation.	Discussion of results based on experiment repetition and / or comparison with other groups. .	Post Lab
PROJECT		
Argue results and draw conclusions	Discussion of results	Post Lab
Use of the model to make predictions in interesting cases	Discussion of results	Post Lab
DECIDE		
Decision-making based on the results	Discussion of results	Post Lab
Communicate and defend decisions	Project: presentation of written report and oral presentation to other groups	Post Lab

Fig. 7. Post-lab questionnaire for the EEQ I subject.

Table 4. Experience evaluation of three subjects

Question		Subject		
		EQ II Level 2	*EEQ I* Level 3	*P* Level 4
1	Laboratory sessions have allowed students to assume an active role and to pose questions concerning the experiment.	4.17	3.68	3.76
2	Previous questions on laboratory experiments were a help for results understanding.	3.70	3.52	3.71
3	Post laboratory questions facilitated the consolidation of the knowledge acquired.	4.04	3.68	3.53
4	End of course assignments allow students to reflect on the connection between lab tasks and real professional situations.	4.13	4.12	3.90
5	Moodle can be a very useful tool in activities organization and planning.	3.48	3.13	3.31
6	Follow up sessions were very useful and well organized by the tutor.	3.04	2.76	3.66
7	The self evaluation of my personal contribution to the group activities was very satisfactory.	3.61	4.2	4.03
8	I feel that practical application is the best way of learning theoretical concepts.	4.61	4.36	4.40

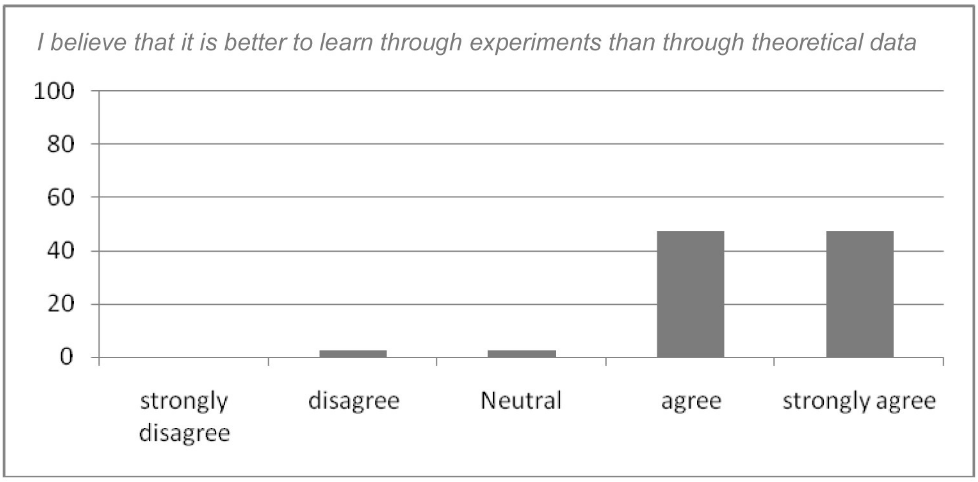


Fig. 8. ‘Learn by doing’ evaluation (Project).

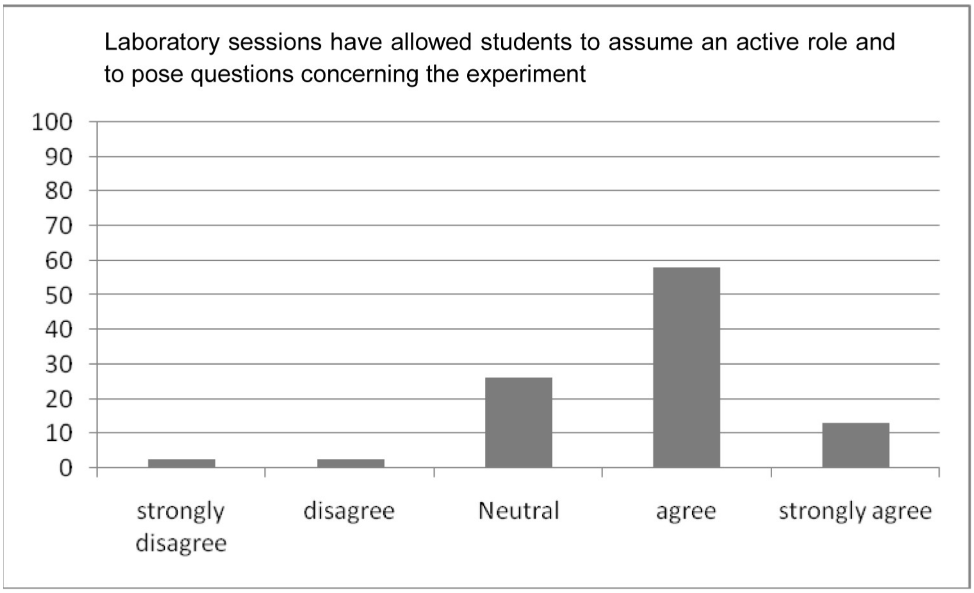


Fig. 9. Question 1 results, regarding the practicality of the laboratory sessions (Project).

With closer observation one can see that, only in two questions (5 and 6) were values found to be lower than 3.5.

Question 5 is reflected by a relatively low score which may be as a result of students not being directly influenced by the use of Moodle.

In question 6 it is interesting to observe that, the ‘Project’ subject, which scored higher, incorporated a weekly tutorial whilst in the other two subjects there were only two tutorials held per year. This result thus implies that students preferred having a greater number of sessions with the professors. In addition, one can also observe that the ‘Project’ subject consisted of 60 students, which provides enough reason for us to affirm that ASM can be applied in relatively large groups.

Such findings suggest that these two aspects must be reconsidered for future studies. Nevertheless, both the participating students and professors alike enjoyed the experience, and the students in particular now have an additional source of motivation as they consider themselves the protagonists in a learning process, ‘learn by doing’, as can be observed in Fig. 8.

If we observe the results of one of the subjects in more detail, for example in *Project* (subject 3) in Table 3, we can deduce that the students’ thought process is based on the same three key stages that we highlighted throughout the development of the ASM: Pre-laboratory, in-laboratory and post-laboratory.

The results of question 1 shown in Fig. 9 (laboratory sessions have allowed students to assume an active role and to pose questions concerning the experience) reveal that 70% of the students agree or strongly agree. Moreover, we can see in question 2

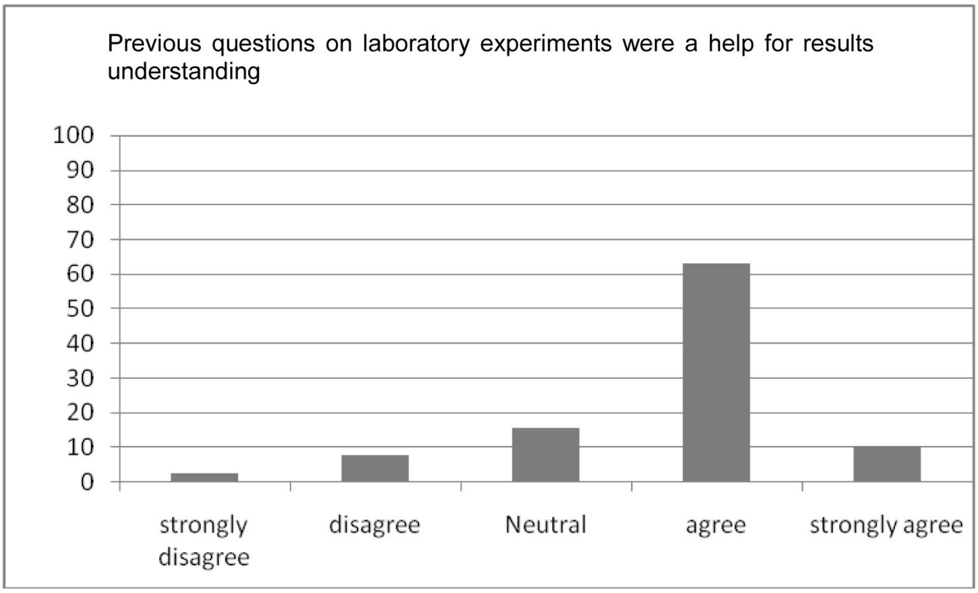


Fig. 10. Question 2 results concerning the Pre-lab assessment. (Project).

that 70 % of the students see the pre-lab questions as being useful (Fig. 10).

One can observe in Fig. 11 (question 4) that the post-lab session is considered a reflection of real professional tasks for more than 80 % of the students (question 3 and 4). We have enabled students to conduct a complete self evaluation of their learning, giving a tremendous value to the post-laboratory step as we can see in Fig. 11 and Table 3 (questions 3 and 4).

We can therefore conclude that the students regard the introduction of the pre- laboratory stage as being very constructive in that they feel this activity aids them in preparing for the learning process in the laboratory sessions to follow. On the same token, they feel that the reflection exercise conducted during the post-laboratory stage is very enriching and useful for the development of other skills such as 'decision –making or drawing conclusions'.

If we focus on the scores obtained in the assignments given as the main post laboratory task in the three subjects, we can observe the evolution of these same calculations as an arithmetical average of all the grades obtained by the students of the three subjects involved in this study.

The EQII y EEQI subjects were grouped together

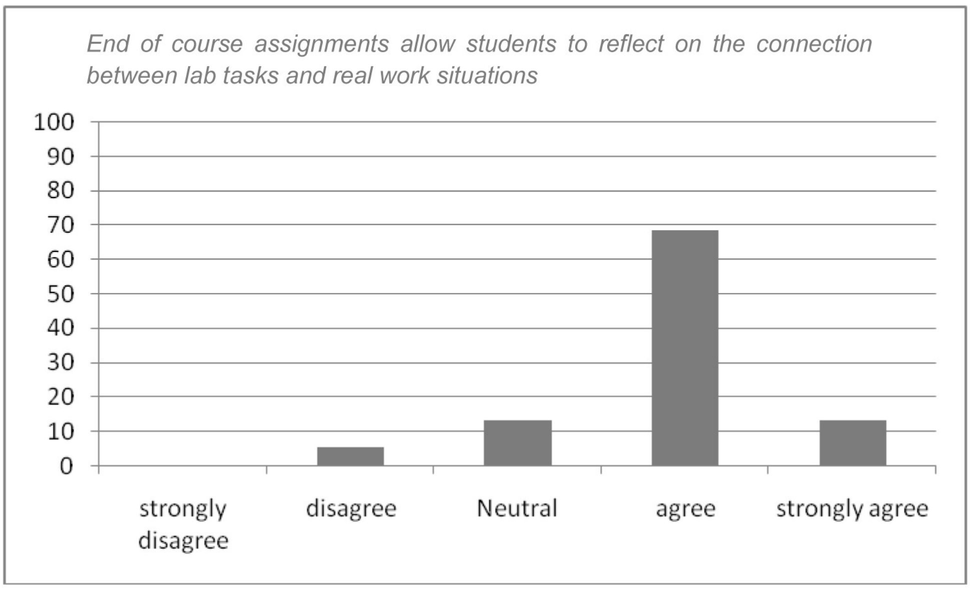
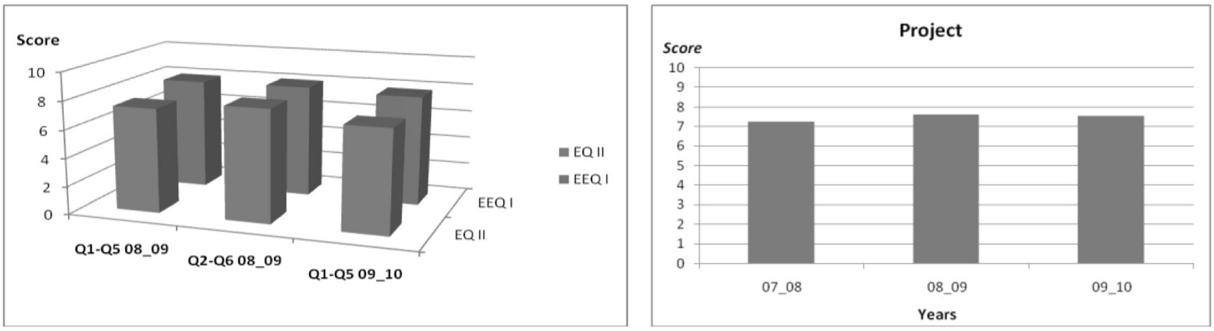


Fig. 11. Post-lab task evaluation (Project).



(a) (b)

Fig. 12. (a) Post-lab evaluation scores (EQII y EEQI). (b) Post-lab evaluation scores (P).

based on their similarity, given that the post-laboratory activities are evaluated based on an oral dissertation or a poster session together with a written report (50%+50%). In addition, both subjects form part of the Chemical Engineering degree with a 20-25% of the total score of 10. An additional common factor is that the work groups were comprised of 4 students with the subjects being based entirely on experimentation. In other words, all teaching took place by way of conducting experiments carried out in a chemical or chemical engineering laboratory. Fig. 12a shows that the final assignment score remains quite consistent over the last three years, albeit with a slight increase in the last two with respect to the first one. Oddly enough, if we apply the same focus to subject ‘P’ in which the final project report, oral presentation, a video and a poster are assessed (60% out of 10), we can observe the same linear tendency of the grades obtained by the students over the last three years (Fig. 12b).

The professors’ view, however, is that whilst the grades may not suggest an increase, a series of elements were observed such as: greater motivation and participation by the students in the final years, plus a higher quality level of assignments that were submitted. One factor that could justify the non-increase in the grades is that this participative methodology helps generate a greater need for the involvement of the student in the development of projects and assignments. Moreover, there are numerous other factors that could explain this linear trend that haven’t been taken into account. One of such could be the difference in the number of students per class per year or per term, their level of preparation and also whether or not the assignments are carried out in conjunction with the rest of their classes etc.

6. Conclusions and future developments

This paper is a presentation of the ‘Applied Scientific Method’ in the Laboratory (ASM) which is a combination of knowledge, skills and approaches that gives students the opportunity to undergo training that will better equip them for the professional world. Judging from the positive feedback of the students we are able to conclude that the ASM serves as an effective factor of learning motivation within the ambit of laboratory assignments and activities. Different complexity levels of the components of this practical skill have been described, and with the definition of skill components and the related elements involved, the identification of different steps of laboratory training (pre-in-post) is made possible. Different factors such as follow-up tutorials to laboratory assignments and the software (Moodle) used must be improved for future applications of the ASM. The application of the ASM in three laboratory assignments of three participating subjects demonstrated the same results in each.

We can therefore affirm that the practical application of the ASM was satisfactory and thus can potentially be applied to any relevant subject.

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Beatriz Amante is a professor of the engineering projects department of UPC-BarcelonaTECH. She has developed several innovative classroom and laboratory activities designed to increase the level of student participation in self-study initiatives. Such activities have been honored with awards for outstanding teaching quality granted by university and government entities alike.

Maria Martinez-Martinez is a chemical engineering professor and deputy director of the Education Science Institute of UPC-Barcelona TECH. She has developed several innovative classroom and laboratory activities designed to increase the level of student participation in self-study initiatives. Such activities have been honored with awards for outstanding teaching quality.

Ana Cadenato is a professor of the department of heat engines of UPC-BarcelonaTECH. She has developed several innovative classroom and laboratory activities designed to increase the level of student participation in self-study initiatives.

Isabel Gallego is a professor of computer architecture and deputy director of the Education Science Institute of UPC-BarcelonaTECH. She has developed several innovative classroom and laboratory activities designed to increase the level of student participation in self-study initiatives.

Nuria Salan is a professor of materials science and metallurgical engineering and the academic coordinator of the Learning Methodologies Research and Innovation program of the Education Sciences Institute of the UPC-BarcelonaTECH. She has developed several innovative classroom and laboratory activities designed to increase the level of student participation in self-study initiatives. Such activities have been honored with awards for outstanding teaching quality granted by university and government entities alike.