Laboratory work renovation through Problem Based Learning in introductory organic chemistry

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Abstract

The Problem Based Learning (PBL) is a methodology which has been an institutional learning strategy in Higher Education in numerous knowledge areas for quite a long time. At the same time, PBL may be a powerful tool to introduce active and student centered learning strategies in conventional educative contexts. The aim of this paper is to describe an example of learning activity whose aim is to integrate the ordinary laboratory work into PBL activities framework. The most decisive stages and the difficult issues in its application are discussed. This sort of activities can allow us to improve social and technological contextualization of laboratory activities and contributes to establish more meaningful relationships with subject matter content. Likewise, the carried out PBL activities have contributed to develop competences like planning and organization ability, search for information and its selection, communicative skills, cooperative work, etc. Particularly, an outstanding increase in the tutorial relationships between students and teacher has been observed.

Key words: Problem Based Learning, Laboratory work, organic chemistry, Science-Technology-Society-Environment relationships.

Resumen

El aprendizaje basado en problemas es una metodología con una larga trayectoria como estrategia de aprendizaje en numerosas áreas de la Educación Superior. Al mismo tiempo, puede ser, en contextos de aprendizaje convencionales, una potente herramienta para la introducción de metodologías activas y centradas en el estudiante. El objetivo de este trabajo es describir un ejemplo de actividad de aprendizaje cuyo objetivo es integrar el trabajo ordinario de laboratorio en el marco de actividades fundamentadas en el ABP. Este tipo de actividades nos permite mejorar la contextualización social y tecnológica de los trabajos de laboratorio y contribuye a establecer relaciones más significativas con el contenido de la asignatura. Asimismo, las actividades basadas en el ABP desarrolladas han contribuido a desarrollar competencias como las capacidades de planificación y organización, búsqueda y selección de la información, habilidades comunicativas, trabajo cooperativo, etc. Particularmente, se ha observado un llamativo aumento de la interrelación profesor-estudiantes en la tutoría.

Palabras clave: Aprendizaje Basado en Problemas, Trabajo de laboratorio, química orgánica, interrelaciones Ciencia-Tecnología-Sociedad-Medio Ambiente.
1. Introduction. Aims of the carried out experience.

1.1. PBL as a tool for methodological renovation in learning chemistry

The actual trends in teaching science are going towards learning models which enhance the main role of students’ activity and their engagement in tasks of high cognitive demand (Kovak, 1999; Felder & Brent, 2004), in inquiry type learning environments. The same way, the reflection on the relationships of their own learning with the social and technological context is also outlined as their commitment with social values as the sustainability. (Vilches et al. 2008) Therefore, each time a greater attention is paid to metacognitive activity (Chrobak, 2001; Parolo et al., 2004) autonomy and self-regulation as a key to be able to lifelong learning. In this way, the creation of learning environments about problematic situations can provide students opportunities to build and to apply the scientific knowledge successfully and to consolidate their acquisition in cooperative and collaborative working contexts. In this educational model the teachers’ role as facilitator, creator and manager of learning environments acquires a greater significance. In summary, all these features configure a very coherent model with scientific work methods and, therefore, particularly useful in the training of future engineers. With regard to transversal competences development, several aims can be emphasized:

- To help students to manage in the Information Society, giving them opportunities to decide what he/she needs to learn to face a problematic situation and acquire searching, processing and information selection abilities.

- To develop characteristic abilities and skills of the engineer’s professional profiles, particularly the communicative ones and cooperative work skills. In this way, a participative view of assessment process must be introduced through self and peer evaluation, encouraging students to assess their own learning process and the educative resources.

- To stimulate the use of tutorial activities, as a privileged tool to change the teachers’ role and the relationship between teachers and students.

- To guide the curriculum from the Science-Technique-Society-Environmental perspective, as a way to give an answer to the challenges which the social context outlines to the future engineers. Likewise, this real-life view must also be related to the business world and, concretely, in rural productive sectors.

According to all the mentioned aims above, to carry out a deeper transformation in the role of laboratory work. This should change its traditional understanding as testing of theoretical knowledge or introduction of certain laboratory skills, merely, towards an inquiry-type approach. Such has been stated by Hofstein (2007): Inquiry-type laboratories have the potential to develop student’s abilities and skills such as: posing scientifically oriented questions..., forming hypothesis, designing and conducting scientific investigations, formulating and revising scientific explanations, and communicating and defending scientific arguments”; In other hand, from a realistic view of our educative context, a higher effort must be done to put in context the laboratory works with regard to rest of curriculum as the social, technological and professional framework.
To face these challenges, PBL is a suitable and well established methodology. Besides its implementation as a curricular comprehensive approach as it is developed in universities like McMaster, Aalborg, Delaware, etc., the application of PBL as a strategy to introduce active methodologies has been the object of a great deal of researches (Paulson, 1999; Mohd, 2007; Kelly & Finlayson, 2007; Gambhir, 2007). In relation to PBL contribution to conventional learning improvement, there is empirical evidence of PBL contribution not only to develop new competences but also to improve the persistence and solidity of acquired knowledge (Ward & Lee, 2002; Anderson et al. 2005) On the other hand, PBL has shown a great adaptability to its use in Information and Communication Technologies contexts by means of educational resources as webquests and collaborative work tools.(Poikela et al., 2007)

With regard to learning chemistry, there are numerous and varied closet o PBL proposals, usually in an experimental way (Selco et al., 2003; Yingjie Lin & Zaiqun Liu, 2003; McDonnell et al, 2007). In many contributions, PBL is proposed as strategy for methodological change (Jones-Wilson, 2005) dealing with its curricular integration (Paulson, 1999; Ram, 1999). Likewise, the PBL contribution to high order cognitive skills development is also justified (Cruickshank & Olander, 2002)

As for the application scope, Duch (2001) describes accurately a framewok to apply PBL in learning chemistry including the course model, the learning cycle, cooperative work Management and assessment. Other contributions are related to concrete activities (Hutchinson, 2000; Wood, 2006) close to case studies (Groh, 2007; Morales & Dienstmeier, 2004) or centered in socioeconomic and professional issues (Karuktsis, 2003). In organic chemistry, the Lehman handbook of experimental activities (1999) can be mentioned, the same way as the active methodologies introduction through PBL activities (Dai Yanfeng, 2004)

1.2. Design of PBL activities: How can we make a good scenario?

According to Duch (2007), the problem nature is a key factor to succesful development of PBL. Their main features must be the following:

1. A good problem must engage students’ interest, and motivate them to deepen into its conceptual understanding. Its subject should be related to the real world, particularly, to students’ professional profile.
2. It must demand the making of decisions or judgements based on the available information. Also, the students should be asked to justify all decisions and reasoning based on the principles being learned. In this way, a good problem should demand students to define what assumptions are needed (and why), to distinguish the relevant information.
3. A problem should be designed in a such way that it requires cooperation from all members and the simple compilation of individual efforts not be an effective strategy.
4. The starting of activity is a key issue for a good problem development. The initial questions must be proposed accurately to achieve the following points:

- All students in the groups should be able to participate in discussion. To reach this goal the questions must comply the following requirements:
They must be open-ended, not limited to one correct answer, and to generate controversial issues which leads to the diverse opinions elicitation. The difficulty level must be placed in the Proximal Zone Development (Vygotsky, 1993), in such a way that their solution are neither obvious nor will take them to a feeling of failure. The students must have the sense of goal achievement, although this may not be too successful. They must be connected to previously learned knowledge and, usually, show an explicit anchorage in everyday knowledge.

5. An effective problem must be clearly linked to content course objectives and, at the same time, to connect the new knowledge to other disciplines.

2. Main features and context of carried out experience

2.1. Essential oils prices as an example of problem based scenario

The use of aromatic plants is deep-rooted considerably in the Mediterranean popular culture and the everyday life of most of our students. An illustrative fact is that at least 70 different plant species are named as “té” in Spain (Pardo de Santayana et al., 2005). In everyday life, their main applications are the herbal tea consumption, their use as flavoring and spices in cookery and folk medicine remedies. They have also been used as insect repellents (basil or clove) for ages as a mothproof (laurel, lavender), etc.

Usually, the aromatic plants are cultivated or gathered to obtain essential oils. These come from a great amount of different types of plants and many different parts of those: leaves, stems, flowers, bark, roots, etc., by means of three extraction methods: cold expression, solvent extraction and, mainly, steam water distillation.

Essential oils are natural valuable products used as raw materials in many fields, including perfumes, cosmetics, household cleaning fluids, aromatherapy, food additives and preservatives, etc. Aromatherapy is the therapeutic use of fragrances to cure, mitigate or prevent diseases by means of inhalation, often combined with massages. For instance, the beneficial effects on the skin of lavender oil are well known.

Nowadays, the increasing ecological awareness is encouraging scientists to study the essential oils biological activity to obtain natural alternative pesticides and weed-killers. In this way, the achievements of chemical ecology (use of pheromones, allelopathical relationships, etc.) arise as a promising resource to go towards a more sustainable agriculture.

From the agricultural point of view, the aromatic plant crops have been, with more or less success, an economic alternative in countries whose soil and climate conditions do not allow other crops as cereal or wine. This is an important issue which must be taken into account as a consequence of its social and demographic impact.

All the reasons mentioned above, justify the introduction of some aspects related to essential oils in agricultural engineering curricula. In the School of Rural Environments and Enology, in the Polytechnic University of Valencia (Spain), essential oils and their chemical composition are dealt with in several subject-matter contents:
In the 1st year, the terpenes and terpenoids structure and properties and their role as secondary plant metabolites are taught in Chemical Foundations of Engineering (compulsory subject). Likewise, the hydrodistillation methods (Clevenger apparatus) to essential oils obtaining is introduced as laboratory activity. Besides, a brief theoretical and practical introduction to GC methods is proposed. In this way, the students can be able to identify and quantify the main components by means of reference standards, Kovats retention index calculation, and peak area normalization without considering response factors. In the following courses, optional subjects like “Natural products” and “Mountain crops”, deal with more detailed topics about aromatic plants cultivation, phytochemical aspects and analytical methods (GC-MS).

2.2. A PBL activity concerning the price differences among essential oils

The starting point of the activity selected as example is the following question:

“Why such a big difference in price among commercial essential oils?”

There is a great difference among the prices of shopping labelled products as “essential oils”. The starting point of the described activity is the surprising low price at which some of them are sold in bazaars and non specialized shops. Their prices contrast with the ones which appear in aromatherapy shops and specialized webpages related to essential oil commercialization. This problem is posed to students by means of a webquest type activity whose main goal is to help students to identify the factors related to price variability.

A first analysis of this variability allows them to focus the problem on agronomic issues as:

- The botanical identity
- The chemotype
- The sort of farming: wild, organic or conventional crop.

Even considering the above mentioned factors, there are still “essential oils” sold as air fresheners which remain too cheap regarding to natural essential oils. This fact must lead students to consider the chemical purity as a source of price variability. Sometimes, the content in a specific compounds has a significant impact in price, as it happens with regard to linalyl acetate lavender content.

To begin with, the essential oils should be produced by purely physical means, be 100% pure and wholly derived from the named botanical source. Chemical composition of these products is subjected to standardization. For instance, the International Organization for Standardization (ISO) defines “Oil of French lavender” as: the oil obtained by steam distillation of recently picked lavender flowers (Lavandula angustifolia P. Miller) either growing wild or cultivated in France”. Its content in linalyl acetate must be between 48 and 58 % and must have a minimum of 0,5 % in camphor. (Lis-Balchin, 2002).

Nevertheless, differences among grades of quality related to chemical purity are usual in aromatherapy and perfumery. Several ways to retail the essential oil prices can be distinguished (Burfield, 2003) Some of them are:

- Addition of single raw materials. These can be undetectable by a gas chromatograph (GC) analysis operating under routine conditions (vegetable or mineral oil) or can normally be materials detectable by GC, for instance, diluents as carbitol (diethylene glycol monoethyl ether or DEGME), diacetone alcohol, Dipropylene glycol (DPG), etc.
• Addition of cheaper essential oils. For instance, the addition of cheaper lavandin
(\textit{Lavandula x intermedia}) to Lavender oil (\textit{Lavandula angustifolia}, L):
• Addition of cheap synthetic components of natural essential oil; for instance, camphor or isobornyl acetate to rosemary oil (\textit{Rosemarinus officinalis} L)
• Addition of isolates or natural components to essential oils, for instance, when pure natural eucalyptol obtained from E. globulus oil (Eucalyptus globulus) is added to rosemary oil

The essential oils obtained from \textit{Rosmarinus officinalis} L and \textit{Lavandula hybrida} (lavandin), have been the ones selected to carry out the proposed learning activity. Both species are characterized by their popularity, versatile use and relevance of considered variability factors, mainly, the numerous amount of botanical varieties and chemotypes.

With regard to lavender essential oil, three varieties are used in aromatherapy (Price & Price, 2002):

• \textit{Lavandula angustifolia}, L with signifiant amounts of alcohols and esters. It is applied, mainly, for respiratory diseases.
• \textit{Lavandula latifolia}, L (spike lavender) with a lower quantity of esters and alcohols, whose main therapeutic uses are as expectorant and in burn care.
• \textit{Lavandula stoechas}, L, also known as french or spanish lavender, which contains about 75 % ketones. It is used as anticatarral, antiinflamatory and cicatrizant

Furthermore, hundreds of natural hybrids between \textit{L. Angustifolia} and \textit{L. Latifolia Medicus}, named lavandins, are also extensively considered as raw materials in essential oils production.

Rosemary has three chemotypes, all of which are used in aromatherapy. (Price & Price, 2002). They are distinguished by the predominance of each one of the following chemical compounds:

![Chemical structures of Camphor, 1,8-cineol, and Verbenone](image)

• Camphor. The main uses of this chemotype are: mucollytic, cholagogic, diuretic, circulatory decongestant, emmenagogic, etc.
• 1,8-cineol (anticatarral, expectorant, mucolytic, fungicidal, bactericidal)
• Verbenone (anticatarral, expectorant, mucolytic, antispamodic, cicatrizarnt and endocrine system regulator)
3. Activity classroom development

The activity described has been developed during four consecutive years in a 1st course of agricultural engineering. It belongs to a set of PBL activities which are introduced to contextualize laboratory work from the STSE relationships point of view and, with regard to methodological issues, to promote an inquiry learning approach.

These PBL activities are carried out by student groups composed of three members during a four month term dealing with introductory organic chemistry. Its assessment contributes as much as a supplementary of 30 % in the course mark. Despite the fact that this sort of activities are proposed as optional, nearly all the students who attend regularly participate in them.

The model for PBL activity development is based on several contributions from literature (Poikela et al., 2007). This is shown in figure 1. This process is accurately coordinated with the theoretical and experimental contents which can be pointed out by students as formative needs to face the posed problem.

*Figure 1: A learning cycle to implement PBL activities in a chemistry experimental course*
3.1. Brief description of each PBL development stages.

Stage 1

The starting point is a webquest (annex 1) submitted to each group of students by means of the ordinary online platform which is used as a tool to develop the whole course content.

The webquest carried out gives the students a first bulk information about the essential oil prices (fig. 2). The great observed differences lead them to be aware of the need of going more deeply into the influence of particular factors as botanical variety, procedence (usually associated to chemotype), organic or conventional crop, etc. (fig.3 )

Figures 2a, 2b. Observed differences among the prices of products commercialized as “lavender oil” (a) and “rosemary oil” (b)
The webquest work ends with an interview whose goal is to establish the chemical analysis as a mean to solve the posed problem and to identify the learning needs to carry it out
• How to obtain essential oils from plants
• How to identify and quantify their main components
• What the chemical nature of these compounds from the organic functional groups view is

Stage 2

An information research about essential oil extraction methods is proposed in such a way that their advantages and disadvantages can be considered. From this discussion, the use of Clavenger apparatus (avalilable equipment in our laboratory) is recognized as a suitable method.

Afterwards, a laboratory session is carried out to obtain essential oil from air dried aerial parts of Rosemary and Lavandin. This is preceded by a prelab activity consisting of a videotape recording and an online test. These concern to physical and chemical foundations of hydrodistillation process as the experimental procedures. The goal of the postlab questions is the identification by students of gas chromatography as a suitable method to identify and quantify essential oil composition. Orientations and guidelines to develop this laboratory work are given in laboratory textbook.

In a later laboratory work dealt with chromatographic methods, samples of natural and the bazaar essential oils are injected in GC equipment. A spreadsheet to calculate Kovat’s retention index from retention times is prepared.

Stage 3

From obtained chromatograms and calculated Kovats retention index, the main components in the analysed samples are identified and quantified aproximately. The comparison between bazaar and natural essential oils shows very noticeable results.

Regarding to lavender essential oil, the presence in both chromatograms of several peaks which match to well known common typical compounds of genus lavender plants are observed (lynalool, lynal acetate, lavandulil acetate, among others) Nevertheless, a great peak (73 % total area) appears in baazar essential oil chromatogram whose Kovat’s RI does not allow its identification as a known essential oil component. This fact can be only interpreted supossing that the known compound is a diluent added to a
natural essential oil. (Figures 4a, 4b). The nature knowledge of this diluent is beyond the goals of this activity, although a GC-MS was performed to identify this compound.

The activity end consists of making conclusions about the surprising low price of baazar essential oil. Besides, the students are encouraged to establish the chemical nature of identified compounds and attempt to find out the natural essential oil chemotype.

*Experimental conditions. The essential oil was obtained in a Clavenger apparatus by means of hydrodistillation during 2 hours. The data were obtained by injection of 1 μL dichloromethane diluted sample in a HP3398A GC Chemstation with a FID detector. The capillary column was a ZB-5 (5% phenyl-95% dimethylpolysiloxane). The carrier gas, N₂ (20 mL/min) and the initial temperature of injector 210°C and 250°C in the detector, with a 1:25 split relation. The initial oven temperature was 50 ºC, maintained for 3 minutes, then raised to 250°C at the rate of 10ºC/min. This temperature was maintained for 10 minutes.*
groups take part to discuss and assess the different contributions. Its main goal is to promote a reflection and synthesis about the overall process.

### 3.2. Assessment

The assessment of activity is carried out into the whole assessment system of PBL activities tied to laboratory work. According to several proposals which have been suggested for PBL assessment (Nowak & Plucker, 1998; Chen-Jung et al., 2004; Sudhir, 2002)

Diagnostic assessment is carried out by means of a structured interview with the group. The assessment during learning process has as main goals to reach a suitable self-regulation and feed-back through a set of pursuit meetings. In these, the foreseen development of activity and the partial outcomes are being confronted. The final assessment is related to the obtained information through:

- The group portfolio, with the information achieved by the group, the laboratory reports, and the meetings reports, etc.
- The final outcomes, in a power-point presentation. Three issues (interest, clarity and formal aspects) are co-assessed by the rest of group members.
- The teachers’ notebooks about the group evolution of participation, autonomy, cooperative working level, etc.
- All this information is comprised into a document which is a tool to mark the student’s performance.
From the social dimension of assessment, the teacher and student’s perceptions about the learning process and the cooperative work method are analysed by means of:

- The notes and reflections collected from the teacher’s notebook through the successive interviews with each group.
- A questionnaire where the following aspects are valued:
  - Suitability of the initial orientations
  - Self-perception of autonomy and motivation
  - Cooperative work features
  - Coherence with the basic knowledge
  - Topic interest
  - Contribution to the subject learning
  - Assessment criteria

### Table 1. Summative assessment. Partial scores for each category

<table>
<thead>
<tr>
<th>Product (oral presentation and debate)</th>
<th>Teacher notebook</th>
<th>Total score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co-assessment</td>
<td>Teacher assessment</td>
<td></td>
</tr>
<tr>
<td>Interest</td>
<td>Adaptation to rules and conventions. Communication skills</td>
<td></td>
</tr>
<tr>
<td>Formal aspects</td>
<td>Magnitudes and units expression</td>
<td></td>
</tr>
<tr>
<td>Clarity</td>
<td>Expression and spelling: accomplishment of orthographic and syntactic rules</td>
<td></td>
</tr>
<tr>
<td>Clarity</td>
<td>Graphic material: quality and pertinence</td>
<td></td>
</tr>
<tr>
<td>Rationale. Theoretical basis and conceptual accuracy</td>
<td>I work really centered in the outlined problem</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Relationship with the basic concepts of the subject</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Presence of concept errors or faulty expression</td>
<td></td>
</tr>
<tr>
<td></td>
<td>To introduce without clarifying terms, initials, etc., directly taken from information sources.</td>
<td></td>
</tr>
<tr>
<td>Quality of used information resources</td>
<td>From higher to lower valuation:</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Searches by means of ordinary resources of the university (databases, e-books, e-journals, etc.)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Spread searches in internet by means of specialized webs and scientific finders. Also, looking for information in manuals of the subject and similar matters.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Restricted but pertinent and suitable searches in internet and manuals enough to achieve minimum information.</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Course learning documents and webpages of general character.</td>
<td></td>
</tr>
<tr>
<td>Autonomy and creativity in learning process (*)</td>
<td>Capacity to formulate and carry out original proposals</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Capacity to make decisions about the development of solving problem process and to plan laboratory work</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Autonomy in searching information</td>
<td></td>
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</table>

4. Concluding remarks: main achievements and found difficulties

The main achievement of these activities is, undoubtedly, the great increase of the students-teacher and students interactions and the tutorial activities encouragement, which is extended to other aspects of subject.
On the other hand, taking into account the high density of theoretical contents, the PBL activities become the only opportunity for the students to develop important competences related to cooperative work, etc.

With regard to laboratory work approach, the PBL activities have been able to create a framework for them. They can convert a recipe in a meaningful activity, in such a way that the students take awareness of agricultural (technological, in general) applications of curricular contents.

From teacher’s point of view, the greatest challenge is probably to define the problem correctly, to adjust its status accurately as open ended activity and to achieve a good enouncement. Besides, all this effort must become an appropriate transmission in the context of the initial activity (interview or webquest type activity)

Another key issue is the most or least experimental nature of the outlined problems. It is not simple to provide an organizational framework for laboratory management which allows to carry out experimental works adapted to the students’ proposals. This way, the PBL model proposed in this paper can be valued as highly satisfactory since in most of the problems which implied experiments, could be carried out correctly. Nevertheless, it is necessary to point out that the teachers overload work may end up being very high. For this reason, it may be necessary to adjust the level of experimental implication of the outlined problems accurately. In the same way, incorporate other ones whose resolution can be carried out with other didactic resources.

A lot of attention should also be paid to the improvement of strategies to search information. A greater effort must be made to provide students opportunities to work with databases, wikis, etc., and, generally, to get a reflexive and critical use of the web, since certain tendency has been observed to appeal to materials excessively divulgative and not excessively rigorous.

The search of a narrow relationship between the content of PBL activities and the learning goals in classroom ordinary activities would be able to restrict a key issue of PBL: the identification by students of their formative needs. Nevertheless, This high relationship between PBL and ordinary classroom activities can be a well justified decision when PBL is implemented with unfamiliarized students with this methodology.

Lastly, it is necessary to highlight the capacity of PBL activities to integrate the students in the subject and encouraging them to participate. Nevertheless, PBL development requires deep changes in educational organization and management, with more flexible timetables and administration of educational resources like the laboratories. On the other hand, these resources must be adapted to new demands outlined by methodologies as PBL, mainly, in all aspects related with the information searching and management, cooperative and collaborative work promotion, self-learning materials development, making virtual environments, etc. This way, the incorporation of information and communication new technologies can constitute an important performance perspective.

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