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EGYPTOLOGY IN THE SERVICE OF LEARNING CHEMISTRY IN INDUSTRIAL ENGINEERING

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Abstract

Ancient cultures or civilizations carried out different technological improvements without the knowledge of the scientific processes involved. At the Escola Tècnica Superior d'Enginyeria Industrial de Barcelona (ETSEIB), some courses deal with the technological achievements in the antiquity and, in particular, one course deals with the achievements of the Ancient Egyptians, not only to learn what the Ancient Egyptians knew and made but also to look for scientific solutions to modern problems related with the antiquity. In this sense, this work considers the teaching of the chemical basis involved in one technological development of the ancient Egyptians which is taught in one Elective Course entitled: "*Questions of technology and civilization in the Ancient Egypt*". The students use their knowledge on Basic Chemistry as well as on Inorganic and Analytical Chemistry in order to understand the chemistry involved in the technological development carried out at the Bronze Age (3000-1200 BC) and propose solutions to the variation in the color of the hieroglyphs painted in papyri. The experience acquired in the lessons taught in the Elective Course together with the feed-back from the students is used to implement a new optional course in the Bachelor's Degrees in Industrial Engineering, Chemical Engineering and Materials Engineering named "*Technological and Scientific Developments in Antiquity: Ancient Egypt and Middle East and North Africa*".

Keywords – Chemistry, Egyptology, Elective Course, Optional Course.

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1 INTRODUCTION

The Degree in Industrial Engineering and the Degree in Chemical Engineering are carried out at the Barcelona School of Industrial Engineering (Escola Tècnica Superior d'Enginyeria Industrial de Barcelona, ETSEIB, http://www.etseib.upc.edu/) in the Universitat Politècnica de Catalunya (UPC-Barcelona Tech) from 1994 and are now in the process of extinction, substituted by the Bachelor's Degree in Industrial Technology and the Bachelor's Degree in Chemical Engineering, respectively). In addition, the new Bachelor's Degree on Materials Engineering has started. The Degrees started at the ETSEIB in the course 2010-2011.

In the former Degrees, some of the credits that the student must make during their studies are related to Elective Courses, including technological and scientific courses but also some humanistic courses, because one of the objectives of the Elected Courses is giving the student a humanistic profile always related to the technological or scientific field. From the course 2010-2011, one of the Elective Courses is called "*Questions of technology and civilization in the Ancient Egypt*" (https://bibliotecnica.upc.es/gd240/ales/51811.pdf QOTCAE, 4.5 ECTS credits) which mainly wants the students:

- To establish the main characteristics of the pharaonic civilization
- To apply scientific and technological concepts learned during the Degree to the technological questions found in Ancient Egypt

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Especially related to the second objective, some technological issues with a chemical basis are taught during the course, e.g. the chemistry behind the pigments used by the ancient Egyptians in their tombs decoration, the chemical reactions involved in the first pigment synthesized in history (the so-called 'Egyptian Blue') and the degradation and chemical reactions suffered by these pigments with time, and the chemistry of the compounds used by the ancient Egyptians in the mummification process.

The course starts with the explanation of the main characteristics of the ancient Egyptian civilization. In this sense, it is noteworthy to say that usually the students do not have a good knowledge on themes such as Ancient History and Ancient Religion, which are critical in order to understand why the ancient Egyptians (and the ancient peoples before the development of the logic discourse) were more interested on the transcendent nature of the things than on their immanent nature. The characteristics explained in the course include history, geography, language and religion, as well as the so-called 'Egyptian Context', the interaction of the Egyptian civilization with other civilizations developed at Greece, Anatolia, Syria-Palestine, Mesopotamia, Iran, and the Arabic Peninsula.

Considering the extinction programme of the Degrees at the ETSEIB, it is scheduled that Elective Courses will finish in 2014-2015. However, in the new Bachelor's Degrees, starting on February 2014 there will be an optional subject at the last semester of the Degrees named "*Technological and Scientific Developments in Antiquity: Ancient Egypt and Middle East and North Africa*" (TSDA), whose syllabus will include some of the themes and objectives of the QOTCAE course.

In this work, in one hand, the methodology to incorporate chemical concepts learned by the students during the Degrees to the study of the ancient Egyptian technology will be discussed and the degree of achievement of the objectives by the students will be tested. This will be done by studying one of the examples taught during the course 2012-2013. On the other hand, the experience gained by the QOTCAE course will be used to help implementing the new TSDA Optional Course in the Bachelor's Degrees in Industrial Engineering, Chemical Engineering and Materials Engineering, the three Bachelor's Degrees taught at the ETSEIB from 2010-2011.

The main benefit of the approaches of the courses is that the students learn not only chemical concepts but also realise that the chemical concepts learned during the studies are useful and applicable to real cases, in particular, in fields which could be thought to be very far from Chemistry or Industrial Engineering, as it is the study of the technological knowledge in the antiquity.

2 DESIGN OF THE COURSE

2.1 General trends

The course consists of 45 hours of teaching at the classroom (in this kind of courses there is not predicted time for homework) distributed in 15 weeks, with two weekly sessions of 1.5 h. The number of students is relatively high, varying from 40 to 60 students per course depending on the year. The different themes together with their approximate duration are shown in Table 1. To the total number of hours in Table 1, the time of the different assessment tasks has to be added in order to reach the total of 45 h.

Subject	***Time duration (h)***
1 Introduction: Mythical Discourse. Geography, Language and Religion of the Ancient Egypt	*9*
2 History of the Ancient Egypt (5000 BC to 30 BC) and interactions with the Near and Middle East	*10*
3 Technological aspects of the Egyptian Pyramids of the Old Kingdom (ca. 2400 aC)	*5*
4 Building and decoration of the New Kingdom tombs (ca. 1500 aC)	*5*
5 The mummification process in Ancient Egypt and Paleopathology	*5*
6 Building, decoration and significance of the ancient Egyptian temples	*5*

Table 1. List of subjects in the course and approximate duration

The evaluation of the students is carried out by means of four different exams during the course. The first exam after subject 1, the second after subject 2, the third after subjects 3 and 4, and the last one after subjects 5 and 6. The student gets her/his qualification after the arithmetic media of the four exams. The exams usually consist of five questions and the students might use books and notes.

2.2 Teaching the chemistry of the pigments used by the ancient Egyptians

This work will be focused in the subject four; Building and decoration of the New Kingdom Tombs, in particular in the chemical composition of the minerals or solids used as pigments by the ancient Egyptians and their possible degradation.

Most Egyptian pigments are the so-called ‘earth colors’, minerals ubiquitously found in the Egyptian landscape which gave black, white, red, yellow and orange colors (see Table 2).

color	***Chemical composition***	***Mineral***	***Period***
Black	C	*Soot*	*All periods*
	PbS	*Galena*	*All periods*
White	$CaSO_4{\cdot}nH_2O$	*Anhidrite, gypsum*	*All periods*
	$CaCO_3$	*Limestone*	*All periods*
	$CaMg_3(CO_3)_4$	*Huntite*	*From Middle Kingdom*
Red	Fe_2O_3	*Red Ochre**	*All periods*
	$\alpha\text{-}As_4S_4$	*Realgar*	*From New Kingdom*
	Pb_3O_4	*Minium*	*Roman period*
	HgS	*Vermilion*	*Roman period*
Yellow	$FeOOH{\cdot}nH_2O$	*Yellow Ochre**	*All periods*
	$KFe_3(SO_4)_2(OH)_6$	*Jarossite*	*From Middle Kingdom*
	As_2S_3	*Orpiment*	*From New Kingdom*
*Orange***	*AsS polymorph*	*p-realgar*	*From New Kingdom*

**Ochre is a mixture of different components that contain iron oxides or iron oxihydroxides. Iron is the responsible of the color, red ochre contains hematite while yellow ochre contains goethite and limonite.*
*** During all the pharaonic period, orange was obtained by mixtures of red (red ochre) and white (limestone)*

Table 2. Minerals used by the Egyptians as pigments

Other colors were not so easily found, especially the blue, because the few blue minerals that could be mined in the Bronze Age did not have optimal properties to be used as a pigment. Azurite ($Cu_3(CO_3)_2(OH)_2$, blue) was sometimes used, but the artisans probably realized very soon that it reacts with atmospheric humidity to produce malachite ($Cu_2(CO_3)(OH)_2$, green) according to:

$$2\ Cu_3(CO_3)_2(OH)_2(s) + H_2O \Leftrightarrow 3\ Cu_2(CO_3)(OH)_2(s) + CO_2(g)$$

The other blue mineral known in the Bronze Age was lapis lazuli, and, in fact, mining of lapis lazuli has been demonstrated to exist at least from 4000 BC in the Sar-e-Sang mines in the Badakhshan district in northeast Afghanistan (Casanova, 2001). Lapis lazuli was used by the Egyptians as a precious stone and arrived to Egypt via a long trade route through Afghanistan, Iran, Mesopotamia, Syria-Palestine and the Mediterranean (Majidzadeh, 1982). However, it was never used as a blue pigment by the Egyptians, probably because the technology to obtain a particle size low enough to give a blue color was not known in Ancient Egypt, and lapis lazuli was not extensively used as a pigment until the middle Ages, when it was named ‘ultramarine’.

Instead of using minerals, Egyptians synthesized a blue pigment, the so-called ‘Egyptian Blue’, $CaCuSi_4O_{10}$, which was found last century as a mineral in the Vesuvius lavas and was called cuprorivaite (Delamare, 2007). The synthesis was carried out, according to Vitruvius, by mixing sand, a copper mineral or bronze and a flux, and heating under oxidizing conditions to 950-1050°C. Under these conditions, the result is the formation of a frit, cuprorivaite and quartz crystals immersed in an amorphous bulk (Pagès-Camagna, Colinart & Coupry, 1999).

In the course, the synthesis is taught in chemical terms. The teacher makes some questions that the students have to respond on the possible reactants, why is sand used? Why a copper mineral? What is a flux and why is it used in the reaction? And, finally, why oxidizing conditions are needed?

Considering the chemical knowledge and, especially, the fact that most students have only made two chemistry courses during the Degree (and in many cases some years ago), these questions are usually difficult to answer. The teacher help is necessary for the students to learn that sand is used because of its content in silica, SiO_2, the copper mineral (malachite or even bronze) is used because of its Cu^{2+} content, the flux is an alkaline mixture of sodium carbonate, sodium bicarbonate and sodium hydroxide which is the medium where the reaction takes place. Oxidizing conditions are necessary in order to oxidize Cu(s) to Cu^{2+} avoiding the formation of Cu^{+}, which easily forms the black copper(I) oxide, darkening the final product.

With the help of the teacher (by means of any critical question), students have to realize at this point that one element is missing: calcium. If an extra addition of calcium as lime, limestone or even shells, is not considered (actually, the Vitruvius recipe does not include any addition of calcium), the only probable source of calcium is the sand. The chemical composition of some Egyptian sands (Table 3) shows that some of them have a relatively high Ca-content and, comparatively, the sands of many places around the Mediterranean have much lower calcium concentrations (Brems et al., 2012). The predominance of low-Ca content in the Mediterranean implied that 'Egyptian Blue' could only be synthesized in few places, such as Egypt and the coast near the Vesuvius.

Origin	*% SiO_2*	*% Al_2O_3*	*% CaO*	*% MgO*	*% Na_2O*	*% K_2O*
Amarna	*87.36*	*2.79*	*5.50*	*0.55*	*0.55*	*0.53*
Amarna	*73.56*	*3.29*	*18.11*	*0.90*	*0.83*	*0.61*
Karnak	*83.61*	*1.32*	*12.01*	*1.23*	*n.m.*	*n.m.*
Pyramids	*82.35*	*1.45*	*8.40*	*n.m.*	*0.19*	*n.m.*
Aswan	*93.78*	*3.59*	*0.67*	*n.m.*	*n.m.*	*n.m.*

Karnak is located near modern Luxor, 'Pyramids' is located in Guiza, Cairo. n.m. means not measured.

Table 3. Composition of Egyptian sands. Data taken from Tite and Shortland (2003)

2.3 Teaching the chemistry of the degradation of the pigments used by the ancient Egyptians. Case study: The whitening of the black hieroglyphs at the Papyrus Bakai

As it is said above, most pigments used by the ancient Egyptians come from minerals easily found in the landscape, and it is expected that they do not alter their color during the millennia. However, in some cases, the colors used by the Egyptians have changed or have suffered degradation with time, e.g. Egyptian Blue or the red obtained with realgar.

2.3.1 Case study: degradation of the black ink in a papyrus

In particular, in the course, the whitening of the black used in one papyrus is studied in detail. The Papyrus Bakai in the Warsaw National Museum (Poland) showed a mixture of black and white hieroglyphs (Figure 1) although it was supposed to be written in black (white was never used as 'ink' for papyrus). Wagner, Donten, Donten, Bulska, Jackowska and Sobucki (2007) studied the papyrus in order to

- know the processes behind the color change;
- propose a methodology to restore the original color of the hieroglyphs.

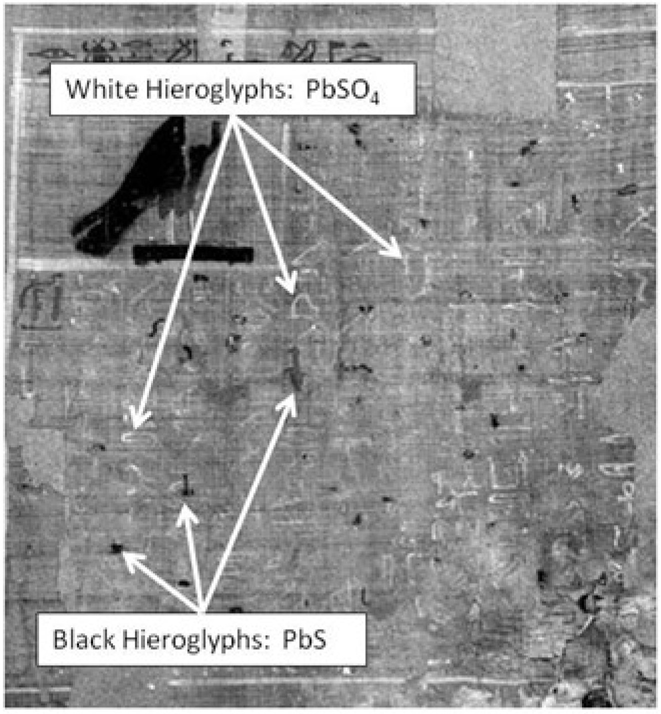

Figure 1. Examples of black hieroglyphs and white hieroglyphs in the Bakai papyrus. Adapted from Wagner et al. (2007)

The main objective of introducing this case in the course is to show the students not only the chemical composition of the pigments but also the chemical reactions derived from the contact of the pigments with the environment. Students at this point already know that PbS(s) was used by the Egyptians as a pigment for the black ink in papyri and now they have to propose the chemical reactions that would explain the whitening of the PbS(s). The teacher gives some clues to the students because most of them do not have a strong knowledge on Analytical Chemistry. One of the clues is an image obtained by Scanning Electron Microscopy with Energy Dispersive X-ray spectroscopy (SEM-EDS) of the hieroglyphs, showing in both the black and the white pigments the presence of lead. As another clue given to the students the teacher reminds the chemical composition of the air and, in particular, the presence of a relatively high oxygen partial pressure. Students should identify the chemical composition of the white 'ink' as well as propose a chemical reaction explaining the black-to-white transformation.

Wagner et al. (2007) proposed that the white ink was composed of lead sulphate and the chemical reaction explaining the color change was a redox reaction where sulfur (from the galena) was the reducing reagent and oxygen was the oxidizing species:

$$PbS(s) + 2\ O_2(g) \Leftrightarrow PbSO_4(s)$$

This reaction is very favored, with log K = 128. The species detected by the EDS were, thus, PbS(s) and $PbSO_4$(s) in the black and white inks, respectively.

After the knowledge of the chemical mechanism of color alteration, Wagner et al. (2007) tried to restore the original aspect of the papyrus. Because the black-white process degradation was an oxidation they proposed a reduction for the white-black process restoration. In this sense, they used one of the most used reducing agents in conservation: sodium tetrahydridoborate, $NaBH_4$.

$$NaBH_4 \Leftrightarrow Na^+ + BH_3 + \tfrac{1}{2}\ H_2(g) + e^-$$

Considering the reduction semi-reaction:

$$PbSO_4(s) + 8\ H^+ + 8\ e^- \Leftrightarrow PbS(s) + 4\ H_2O$$

The global redox reaction would be:

$$PbSO_4(s) + 8\ NaBH_4 + 8\ H^+ \Leftrightarrow PbS(s) + 8\ Na^+ + 8\ BH_3(g) + 4\ H_2(g) + 4\ H_2O$$

However, the results were as expected from a 'macroscopic' point of view but could not be the expected considering the chemistry of the process involved. The white hieroglyphs did change their color to black but the reducing species used in the restoration of the papyrus, $NaBH_4$, instead of reducing sulphate to sulphur could reduce Pb^{2+} to Pb(s) which could be the species responsible of the black color of the hieroglyphs:

$$PbSO_4(s) + 2\ e^- \Leftrightarrow Pb(s) + SO_4^{2-}$$

The global redox reaction being:

$$PbSO_4(s) + 2\ NaBH_4 \Leftrightarrow Pb(s) + SO_4^{2-} + 2\ Na^+ + 2\ BH_3(g) + H_2(g)$$

Considering if a chemist could have predicted the restoration mechanism by using redox reactions, it is important at this point to make the students thinking over the applicability of Chemistry to Egyptology (or the applicability of Egyptology to Chemistry). In addition, students should also ponder the place of the chemist and the egyptologist in the process of studying an ancient Egyptian artefact, being aware of the different expertise of both specialists (see, for example, Figure 2 on the fields of expertise of chemists and egyptologists in the study of the black color degradation in papyri).

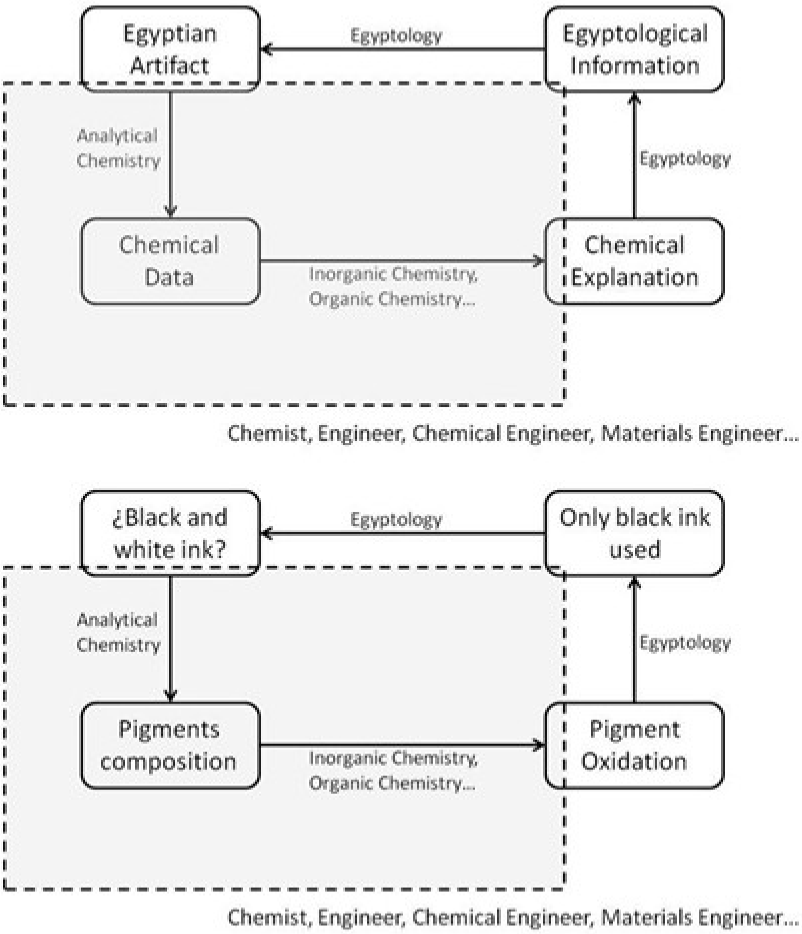

Figure 2. Scheme of the science-egyptology synergy on studying an egyptological chemistry-based process. The grey rectangle indicates the field of expertise of a Chemist

3 RESULTS AND DISCUSSION

It was important to know at this point the opinion of the students about the adequacy of the chemical concepts they knew with the real chemical problem dealing with the degradation of the black pigment in the papyrus. For this reason, a test was given to the students with some questions that they had to answer anonymously. They have to punctuate 1, 2, 3 or 4 (1 completely disagree, 2 disagree, 3 agree, 4 absolutely agree) the following questions:

- (1) I understood the egyptological part of the problem with the papyrus (importance of the colors used, context of the papyrus, provenience...)
- (2) My chemical knowledge was sufficient to understand the chemical processes involved in the degradation process as well as in the restoration process
- (3) I have learned/reminded chemical concepts
- (4) I have learned some egyptological concepts

The four questions were prepared in order to obtain information on the most significant aspects:

- adequacy of the example to the egyptological concepts learned,
- adequacy of the example to the chemical concepts learned before the course, and
- usefulness of the example for learning chemistry and egyptology.

In addition, although the test was anonymous, the students had to include more ‘technical’ information related with their studies:

- Indicate your Degree
- Indicate the courses of chemistry you have passed during your Degree and when you passed them:

Number of courses:

Basic Chemistry	X years ago
Analytical Chemistry	X years ago
Inorganic Chemistry	X years ago
Others (indicate)	X years ago

These data are especially important in order to explore the responses given to question number 2.

The results obtained in the questionnaire are shown in Table 4. This table only shows the results of the responses given by the students of the ETSEIB in the Industrial Engineering Degree and the Chemical Engineering Degree, whose syllabi are very similar to the ones of the Bachelor’s Degree in Industrial Engineering and Bachelor’s Degree in Chemical Engineering, in which the future Optional Course will be included.

Questions 1 and 3 are related to the egyptological concepts taught and learned, and, according to the students, the explanations given were enough in order to understand the importance of the study explained and the example was useful in order to learn historical/egyptological concepts, because all the responses are situated between the “agree” and the “absolutely agree”. The results are very similar for both degrees, as expected because before the explanation the students have similar egyptological knowledge independently on the Degree.

Question	***Industrial Engineering***	***Chemical Engineering***
I understood the egyptological part of the problem with the papyrus	*3.8*	*3.8*
My chemical knowledge was sufficient to understand the chemical processes	*2.8*	*4.0*
I have learned/reminded chemical concepts	*3.2*	*3.2*
I have learned some egyptological concepts	*3.3*	*3.2*

Values are given with an error of ±0.2, Number of students: 35 from Industrial Engineering and 10 from Chemical Engineering

Table 4. Results obtained in the questionnaire

However, there is a clear difference when considering the responses of the students of both degrees to the question 2, what deals with the chemical concepts of the students before the explanation. This difference was also expected due to the own syllabi of the degrees. Obviously, students of the Chemical Engineering Degree have learned more chemistry than students from the Industrial Engineering Degree, which study chemistry only during the first year. In addition, according to the questionnaire, the last time the students of the Industrial Engineering Degree learned chemistry was more than 4 years before the present course. On the other hand, the response to question 3 (related to the new chemistry learned during the example) was similar in both degrees and the results were once more between the ‘agree’ and the ‘absolutely agree’, what means that in spite of a different previous level of chemistry all the students have learned new chemical concepts.

One of the objectives of this work was using the information obtained by the students in order to plan and prepare the course in the Bachelor’s Degrees. In this sense, some differences between the Elective Course QOTCAE and the Optional Course TSDA should be considered:

- Optional Courses are planned to be carried out at the final semester of the Bachelor Degrees and do not accept students from earlier semesters (see Figure 3), while in the Elective Courses, students from any semester are accepted.

- The Optional Courses are planned only for three Bachelor's Degrees (the ones taught at the ETSEIB): Industrial Engineering, Chemical Engineering and Materials Engineering. In both Degrees, students make at least two basic chemistry courses (during the first two semesters of the Degree). Students from the Bachelor's Degree in Chemical Engineering study in addition Analytical Chemistry, Organic Chemistry and Experimental Chemistry during the third semester http://www.etseib.upc.edu/ca/portal-dassignatures.

The Optional course shows a higher homogeneity of students than the Elective Course and also a minimum chemical knowledge of all the students.

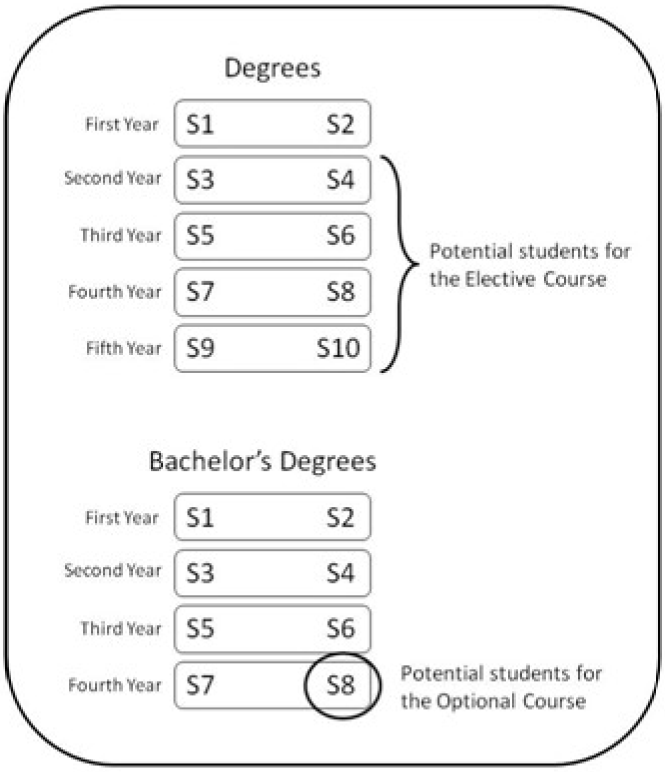

Figure 3. Situation of the Elective (Degrees) and Optional (Bachelor's Degrees) Courses in the Syllabi. SN represents the semester number N

Perhaps the most interesting trend observed in the response of the students of Industrial Engineering to the questionnaire was the necessity of having more chemical knowledge related to the examples explained during the course. In this sense, an adequate solution would be giving the students tasks outside classroom related with the concepts that will be taught (e.g. redox chemistry in the Papyrus Bakai example). The adequacy of the concepts learned with the homework could be tested in the classroom by means of a short questionnaire or even some questions put to some students. This adequacy should also be tested after the teaching by using a similar questionnaire to the one shown in this work but also considering the results of the exams where such examples will be included.

However, one of the main differences of the students coming from the different Bachelor's Degrees will stay the different previous chemical knowledge. In this sense, a possible solution could be to establish different homework for the different Bachelor's students. Industrial Engineering and Materials Engineering students should learn before the teaching concepts related with the basics of the redox reactions (e.g. oxidation, reduction and stoichiometry of the redox reactions).

4 CONCLUSIONS

The objective of the QOTCAE Elective Course coincides with the main objective of the Elective Courses offered at the Polytechnic University of Catalunya: to introduce the students to the humanistic knowledge with the help of science and to learn science with the help of a humanistic matter. The teaching of the course permitted to gain experience on teaching chemistry with the help of Egyptology, experience that, as it will be described below, will allow preparing a new course. However, the study of the technology of the ancient civilizations usually needs knowledge on at least two different subjects: the scientific/technological knowledge and the historical/anthropological knowledge.

The necessity of a basic knowledge on both subjects (in this work Chemistry and Egyptology) opens the application of a wide range of educational aspects but the feed-back with the students is critical. In this sense, it is strictly necessary to know the opinion of the students. The responses to the questionnaire presented in this work were between the “agree” and the “absolutely agree” but in one case, related with the adequacy of the level of chemistry of the students before the example taught. The results have shown that, as expected, students make the Elective course with a chemical knowledge that depends on the Degree and, in addition, responses of the students from the Industrial Engineering Degree were between the “disagree” and the “agree”.

This is evidence that must be considered during the planning and the preparation of the Optional Course that will start in February 2014. In order to accomplish its objectives, the previous knowledge of chemistry of the students should be carefully controlled and equilibrated. This could be done by different tasks that students have to make before the classroom, such as responding to questionnaires of chemical concepts with the help of both a short theoretical summary and bibliographic recommendations.

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