E-QUESTIONNAIRES IN THE CHEMISTRY CURRICULUM: ARE THEY USEFUL ICT TOOLS FOR ECTS COMPETENCE ACQUISITION IN THE CHEMISTRY LABORATORY?

Manuel Miró*, Javier Llorente, Joan Perelló, Fernando Tur

Department of Chemistry, University of the Balearic Islands (SPAIN)

Abstract

E-tools based upon Information and Communication Technologies (ICT) are prevailing asynchronic activities within the Bachelor Curricula at European Universities as per the European Higher Education Area (EHEA) guidelines. The aim of this communication is to evaluate the role of Moodle questionnaires as an active asynchronous ICT platform to promote students self-learning and acquisition of procedural competences in the chemistry laboratory along with lab security rules and norms. This is to be applied to a course of General Chemistry of a heterogeneous group of first year students in the Agriculture Engineering Bachelor at the University of the Balearic Islands (UIB), Spain.

The actual applicability of e-questionnaires is explored in three different scenarios: i) evaluation of the prior knowledge of students in concepts related to the lab exercises, sometimes already discussed in synchronous activities in the class (pre-lab evaluation), ii) helping students in understanding new principles or reactions before execution of the practical tasks in the lab (pre-lab evaluation); iii) following and rating the degree of competence acquisition after undertaking the lab course (formative and post-lab assessment).

The project involves a first step of generation of a pool of questions and answers (including feedback) in the format of multiple options for every individual lab exercise with a single correct answer. This is followed by the e-questionnaire generation, which is posted in the Moodle platform at UIB and open for answer within a given timeframe (typically 2-3 days), whereupon the marks and correct answers will be delivered. We do also investigate how attractive self-prepared images and videos are in terms of identification of appropriate unit operations in the lab and avoidance of prevailing lab misconcepts.

We do also present results on how Moodle questionnaires are rated by the students themselves (via hardcopy surveys) as compared to other asynchronous or synchronous models of teaching & learning competences in the chemistry lab curriculum before starting lab work including: i) reading of the laboratory scripts, ii) teacher explanation of the lab exercises, iii) students' self-writing of the script on the basis of the exercise aims, iv) collaborative learning in groups followed by presentation of the aims and the script summary to the remainder of students and v) minimal pre-lab tasks and acquisition of overall theoretical knowledge from experimental results. We finally propose measures to solve potential cons identified in using Moodle questionnaires allied to undergraduate chemistry lab task learning.

Keywords: e-questionnaires, chemistry, laboratory curriculum, unit operations, undergraduate students, agriculture engineering Bachelor.

1 INTRODUCTION

Blended learning is currently deemed as an emerging trend in higher education regardless of the Bachelor curricula inasmuch as it affords the judicious combination of asynchronous Internet technology with face-to-face learning [1,2]. In this context, novel interactive teaching & learning models have been launched based upon the development of virtual e-learning environments involved in the Web 2.0, such as asynchronous (forums) or synchronous (chats) including e-questionnaires within Virtual Campus platforms [3,4,5].

In previous communications [6,7,8,9] we have proven that e-questionnaires are valuable tools in formative assessment procedures for the acquisition of students' expected competences as per EHEA guidelines [10] in courses of General Chemistry in distinct Bachelor degrees (Chemistry, Physics, Biochemistry and Agriculture Engineering) as applied to students from the UIB. These questionnaires also support educators in getting information on students' prior knowledge in basic chemistry concepts, and students in subject evaluations, e.g., written exams preparation.

This study is aimed at expanding the applicability scope of e-questionnaires to asynchronous teaching and learning of security and safely rules along with basic unit operations in chemistry laboratories, as exemplified in a first-year course of General Chemistry for agriculture engineering bachelor students at the Polytechnic School of UIB (academic course 2013-2014). It should be noted that the chemistry lab curricula in first year students of any degree at the UIB usually encompasses traditional "cookbook" experiments where students simply follow a lab manual, but no efforts are given toward guided-inquiry laboratory experiments (GILEs) [11], in which students have considerable autonomy in the design and execution of the lab experimental workload. We do foresee GILEs as being a novel pedagogical tool in promoting students' learning, improve their critical thinking, promote teamwork and improve students' leadership skills, all in line to cope with EHEA expectations in student-centered learning scientific courses.

In this context we will evaluate the role of e-questionnaires in assisting students in the understanding of new principles or reactions before execution of the practical tasks and detect misconcepts and deficiencies in basic concepts from high school education as related to the chemistry lab curriculum. The role of images and videos taken during lab exercises in stimulating students' learning will be discussed in detail. Validity of e-questionnaires in formative assessment and post-lab evaluation tool will be also investigated in the context of chemistry lab courses. Experimental research data is to be critically compared with results obtained in a pilot course of the same degree but from the academic year 2012-2013, where e-questionnaires were not applied to the lab curricula.

2 EXPERIMENTAL APPROACH AND RESEARCH METHODOLOGY

The project started with the authors' coordination to set the competences to be gained in the General Chemistry laboratory course for agriculture engineering students (possibly extended in the future to first-year undergraduate students from other degrees) on the basis of which the contents of the course description were elaborated. The following experimental approach was utilized:

1. Organization of the teaching curriculum for lab classes in several blocks/themes according to the generic, transversal and specific course competences to be acquired as per syllabus guidelines. In our case, the course breakdown consisted of six distinct blocks, each corresponding to one lab exercise as follows:

A. Paper chromatographic separation of plant pigments. Evaluation of different fertilizer inputs.

B. Qualitative assays. Assessment of acid-base, precipitation, complexation and redox reactions.

C. Determination of bioaccessible phosphorus in solid fertilizers by heteropolyacid formation.

D. Determination of soil pH. Concept of soil buffer capacity.

E. Principles of organic chemistry. Implications to soil chemistry.

F. Determination of water hardness via complexometric titration.

2. Generation of a pool of queries with corresponding answers (minimum of 15) for each of the lab exercises detailed above. The whole pool was compiled within a "dummy" subject called "Moodle Questionnaires in General Chemistry lab" and launched within the Virtual Campus platform (in our case Campus Extens) to which the overall participants of this project have full access. The "dummy" subject allows participants to export the whole pool (or a range of questions) to their own PC and manage them separately.

From the variety of query types available in Moodle questionnaires including short answer, true/false, numeric answer, cloze-type, multiple options with a single or multiple answer and paired query/answer (Q&As), we decided to built the pool of questions capitalized on multiple options (namely, four answers) with a single correct answer and paired Q&As as well. The database could not be used directly to generate an accessible questionnaire to the students. In return, the Q&As in each individual lab exercise must be initially exported in a GIFT format from the dummy General Chemistry course and then imported by the educator into the on-line platform of the Agriculture Engineering course to which the students will have now full access.

3. Individual preparation of e-questionnaires from the pool of Q&As in Moodle and use them in pre-lab tests (assessment of students prior knowledge and support GILEs) and post-tests (final lab exam). For pre-lab tests, we usually post the fundamentals of the exercises in the on-line platform as a Word or ppt files but do need further elaboration by the students themselves so as to trigger self-learning abilities. Regardless of the lab exercise and aim of the test, e-questionnaires consisted of a list of 10 to 15 queries selected from the whole list in the database, and opened for answer within a specific timeframe (usually 2-3 days) in the week before the given lab course was scheduled (pre-lab questionnaires) for a total time of 60 to 90 minutes from the kick-off. Final evaluation (post-lab e-questionnaires) was performed in a synchronous mode on the date specified in the teaching guide of the subject. Any failure in the answer entailed a -0.25 point from the overall mark. Whenever possible, educators' feedback was added to the solutions in each individual question to guide students to the correct answer via useful hints. To overcome potential fraud in pre-lab questionnaires, the correct choices were merely displayed once the questionnaire was closed and random questions (whenever possible) were displayed per individual students with no possibility of copying Q&As, and paste them onto external Word files.

4. Evaluation of students' performance and engagement in lab courses as compared to previous years in courses where the new model of e-learning was not applied.

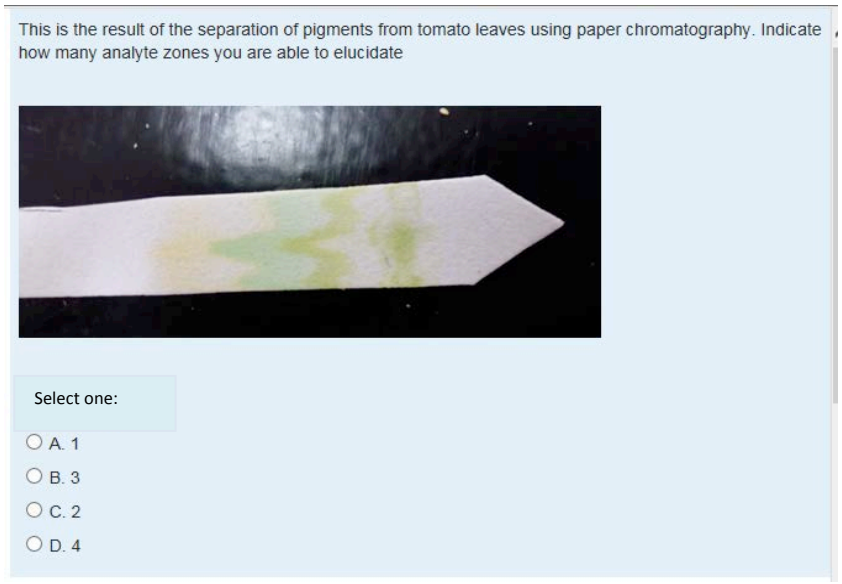
5. Preparation and delivery of a survey (at the end of the course) to get knowledge of students' background on blended learning and their perception of GILES and e-questionnaires as utilized in the lab course.

6. Critical evaluation of this new ITC in the chemistry lab curriculum from the perspective of teachers and suggest improvements for the upcoming years based on experimental data. Statistical data treatment including data correlation via least-squares regression lines, lack-of-fit tests, Student t tests and bar diagrams was performed using Microsoft Office Excel 2010 (Redmon, Washington, USA) and Sigma Plot 11.0 (Systat Software, Inc., San Jose, 2008).

NOTE: For ethical issues in educational projects, the anonymity of experimental individuals participating in this project is assured. In addition to privacy, principles of equity, autonomy, harmless and reciprocity applied to the experimental design and results obtained likewise.

3 RESULTS AND DISCUSSION

For proper assessment of the experimental research data obtained in this study, the particular characteristics of the undergraduate students in the agriculture engineering bachelor should be explained in detail. In fact, this is a very heterogeneous group with ages ranging from 18 to 38 year and with a large number of individuals with a social, humanistic or technological rather than scientific background, or with a professional technical education. Most importantly, ca. 15% of students combined University studies with family related tasks or partial to full-time jobs. Hereto, this current study investigates on the basis of students learning outcomes the effectiveness of Moodle questionnaires as a complementary online learning experience to assist those students who demand a great deal of attention in cognitive and unit operations in the chemistry laboratory because of limited grounds in the subject. As detailed under Experimental the pre-lab e-questionnaires were open within a given timeframe prior to start each of the six practical lab exercises and a number of 32 students out of 46 completed the six on-line questionnaires. This entails participation greater than anticipated taking into account that this internet-based education tool was used by none of the educators but two (from algebra and mathematical analysis) in the remainder of subjects within the first-year course and never applied to laboratory based courses. Examples of questionnaires with embedded videos and images in which students are asked to identify appropriate glassware and instrumental handling, visualize distinct types of reactions for qualitative analysis and identified inappropriate lab operations are shown in Fig. 1.



A)

B)

Figure 1. Illustrative examples of images and videos used in Moodle questionnaires in pre-lab tests. A) Example of qualitative analysis to identify pigments bands and discern the actual bands from the sample application band. B) Video to illustrate the sample preparation steps to determine bioaccessible phosphorus (Olsen Method) in solid fertilizers

The final lab scores in this course were calculated from the average of the six pre-lab asynchronic e-questionnaires scores (20% of lab score) plus the score of the synchronic post-lab e-questionnaire test (40%) and the resolution of queries related to the lab exercises to be answered by teams of two students and delivered to the educator the week after undertaking the lab exercise (40%). In figure 2, the average of scores from Moodle pre-lab questionnaires (ranging from 0 to 10, being the latter the best) was represented against the final lab scores per individual students using the software package Statgraphics Centurion XV.I. The least squares plot with a correlation factor of 0.704 indicates a moderately strong relationship between the scores of pre-lab e-questionnaires and those of the final lab scores. This was supported by the evaluation of the lack-of-fit test of the linear model affording $p=0.874$ (> 0.05) which suggests that the linear model appears to be adequate for the experimental data at the 95% confidence level.

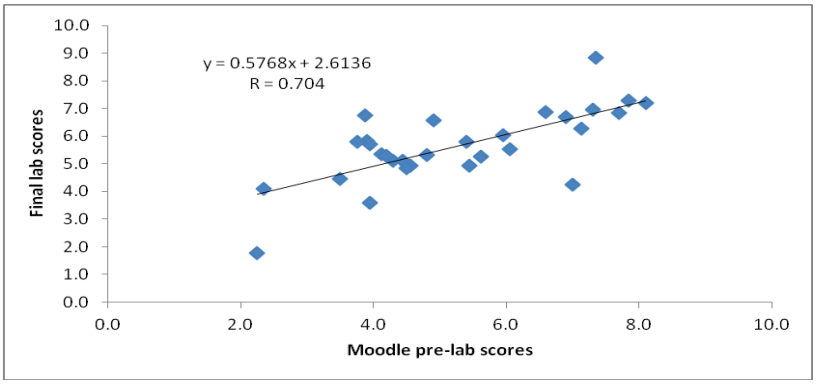


Figure 2. Investigation of potential straight-line correlation between scores as obtained from Moodle pre-lab questionnaires and those from the final lab scores.

Notwithstanding the fact that the slope and intercept of the linear plot are significantly different from 1 and 0, respectively, thus indicating that the absolute scores of the pre-lab e-questionnaires differ from the final lab scores, the acceptable correlation factor between X and Y ($r > 0.7$) demonstrates that pre-lab e-questionnaires play a significant role as a formative evaluation tool so as to provide undergraduate students of agriculture engineering reliable measures to keep track of their learning outcome in terms of cognitive and procedural lab competences and the actual expectations of passing the overall lab exercises of the course.

Further, we have investigated the potential formative assessment credentials of pre-lab questionnaires for the learning of the themes and concepts of the subject wherein besides lab scores (20% of final course score) theoretical intermediate and final exams accounting for the 30 and 45% of final score and the resolution of exercises in the backboard (5 % final score) were used for student rating as well. Experimental results compiled in Fig 3 revealed that ca. 50% of students who passed the Moodle pre-lab questionnaires (average ≥ 5) gained the overall cognitive and practical competences set within the course description but merely 20% of students who failed the pre-lab questionnaires passed the subject. These results are in good agreement with previous findings in the use of e-questionnaires in courses of General Chemistry in distinct bachelor degrees at the UIB, e.g., Chemistry, Physics and Biochemistry [6-9].

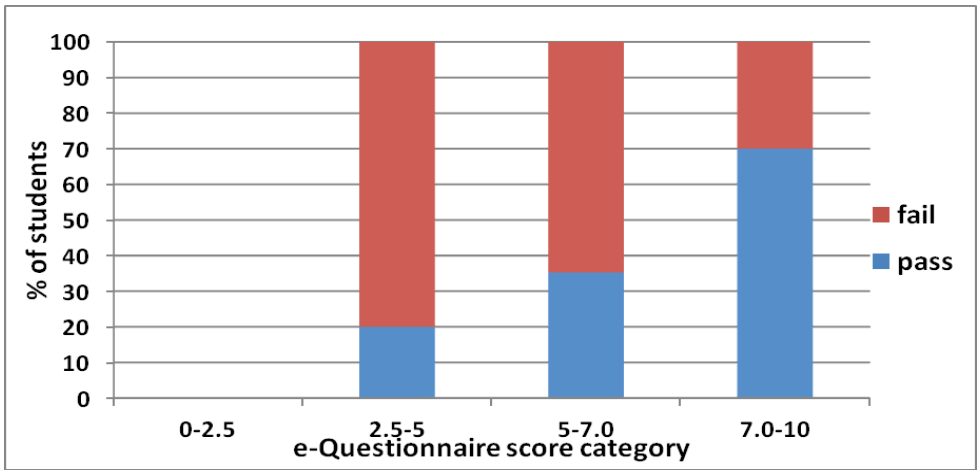


Figure 3. Bar diagram illustrating the percentage of students who passed / failed the subject of General Chemistry as compared to the average score in the pre-lab e-questionnaire (n=32).

The experimental results obtained in this course and illustrated in Fig. 3 were compared against a control group of 32 undergraduate students from the same Bachelor degree and subject, undertaking exactly the same six lab exercises in the course 12-13 but without using Moodle questionnaires as pre-lab and post-lab ICT tool. Processed data revealed that in both cases the absolute and relative number of students who passed the subject at the end of the semester (regular examination period) was the same, namely, 14 out of 32, but we have observed a significant number of students who obtained the highest scores (namely, 7-10) in the course 13-14, viz., 8 out of 32 against 2 out of 32

students in the course 12-13. These results indicate that pre-lab e-questionnaires are deemed most useful for those students with a solid background in chemistry and engaged in the subject to assist them to gain better scores, but do not seem on the basis of this study to improve the outcome and performance of those students with limited knowledge in the subject, e.g., those who entered the University from technical schools (i.e., they did not attend advanced courses to get prepared for University bachelors) or from high schools but merely undertaking technological subjects in which chemistry is excluded.

To get insight into the perception of the agriculture engineering students to novel teaching & learning ICT tools as compared to classical educator-centered approaches, and most specifically, the role pre-lab Moodle questionnaires play for autonomous learning of unit operations and procedures in the general chemistry lab, we prepared a survey consisting of 8 queries which was delivered to the students so as to get answered on a volunteering and anonymous basis. We have received the survey fully answered from 24 out of the 46 students participating in the lab exercises (but merely 32 students regularly attended the theoretical classes, seminars and tutorials).

The first query asked whether students undertook high school courses and if so whether they learnt advanced chemistry. Survey data revealed that only 42% (10 out of 24) studied advanced chemistry in the year before entering the University. This explains the large percentage of students' subject failure (> 55%) observed in this current study.

The second query asked whether students ever attended chemistry lab exercises in high school. 13 out of 24 students at least on one occasion attended lab demonstrations, but only in training courses at intermediate chemistry levels. This explains the difficulties observed during the lab practical courses for a large number of students to appropriately use the lab glassware, instrumentation, apparatus and/or conduct basic lab operations that are expected to be acquired in science subjects at high school.

The third query was phrased as follows: In terms of knowledge acquisition, what do you think that best suits you: the explanation of theoretical concepts related to the lab exercises before or after the execution of the tasks in the chemistry lab? A large number of students (20 out of 24) do prefer the conventional and most straightforward learning mode, that is, the explanation of the lab tests in a cook-book format by the educator. However, a small number of students selected a more innovative format involving the learning of basic concepts and unit operations before the lab exercises and a more thorough explanation of theoretical principles afterward.

The fourth query was the main core of the overall survey and asked students to rate by themselves (0-10, the latter being the best score) distinct asynchronous or synchronous models of teaching & learning competences in the chemistry lab curriculum before starting lab work including: A) reading of the laboratory scripts, B) teacher explanation of the lab exercises, C) pre-lab e-questionnaires, D) students' self-writing of the script on the basis of the exercise aims, E) collaborative learning in groups followed by the presentation of the aims and the script summary to the remainder of students in a synchronic mode and F) minimal pre-lab tasks and acquisition of theoretical knowledge from experimental results.

Experimental data from the survey is collected in Fig. 4. The average scores of the six distinct teaching and learning approaches (A-F) were 7.5; 7.6; 5.5;7.0; 4.1 and 6.1 for methods A,B,C,D,E and F, respectively. According to these results and individual lab scores illustrated in Fig 1 students do prefer conventional learning methodologies based on following a cook-book script (graph A) or the educator explanations (graph B) as these two methods received the highest scores. On the other hand, poor scores were obtained by a GILEs-type mode (graph E) and pre-lab Moodle questionnaires (graph C), which is attributed to the fact that students perceive these innovative ICT tools as extra burdens (rather than innovative tools to trigger their learning abilities) in the EHEA educational model based on continuous assessment. These results are in good agreement with previous observations of other researchers utilizing GILEs in chemistry subjects [11]. Surprisingly enough, another GILEs-type educational mode (graph D) involving the self-writing of the lab script by individual students received a high score. However, this learning mode was not utilized as ICT in the course of General Chemistry for agriculture engineers. As opposed to the pre-lab Moodle questionnaires students were most likely unable to foresee the implications in terms of autonomous study that this ICT tool would entail.

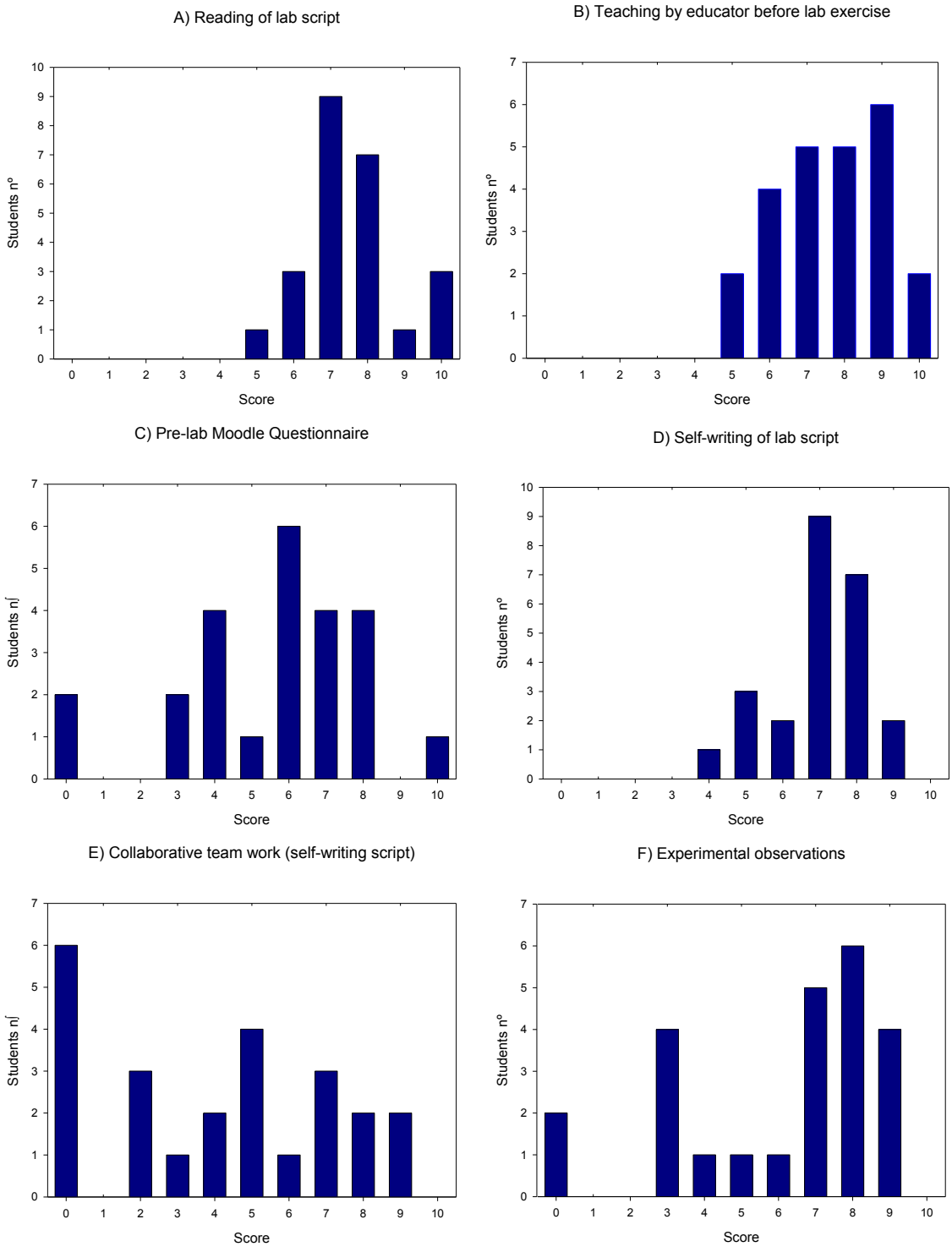


Figure 4- Bar diagrams illustrate students' rating (from 0 to 10) of varied (conventional and innovative) teaching &learning methodologies in chemistry lab courses.

As a follow up of the former query, the fifth question asked the students to select two of the above teaching&learning methods (A-F) for concurrent use in the chemistry lab curriculum. The preferred pair of methodologies was A-B (7 out of 24 students) as might be expected from previous students' ratings, corroborating the fact that the conventional cook-book style and pre-lab educator teaching are deemed most appropriate by first-year undergraduate students to learn experimental-based competences. The second choice was the pair B and D (4 out of 24 students). In this case, students claim that a judicious combination of synchronic educator teaching and asynchronic GILEs-based

homework is most appropriate for further elaboration of the lab script and learning basic lab-related concepts.

The last three queries of the survey aimed at receiving the students' perceptions of the use of videos and illustrative images embedded in the Moodle questionnaires and getting knowledge on the previous use of e-questionnaires in other subjects of the course. Survey answers revealed that only the educators in maths used this ICT. The students' scores (0-10) about the utility of images and videos in the e-questionnaires averaged 7.7 and 7.5 (n=24), respectively, which were superior to the score received by the e-questionnaires themselves (graph C in figure 4). This is attributed to the fact that images and videos stimulate students to visualize critical experimental tasks in the lab and detect incorrect usage of glassware, analytical instrumentation and inadequate performance of basic lab operations.

4 CONCLUSIONS

This research article was aimed at investigating the role of e-questionnaires as novel ICT in the chemistry laboratory curriculum based on student learning and engagements. As a proof of concept it was applied to first-year undergraduate agriculture engineering students within the course 2013-2014. Experimental results evidenced that pre-lab e-questionnaires served as a formative evaluation tool for students and educators about the acquisition of competences related to experimental work but theoretical principles as well. However, this study indicates that Moodle questionnaires only assisted those students with good grounds in chemistry as obtained from advanced chemistry at high school for expedient acquisition of lab curricula competences. Further research work is currently underway to expand the applicability scope of this project to other bachelor degrees (including chemistry) and subjects on advanced chemistry laboratories to demonstrate the above hypothesis.

The perception of students for e-questionnaires is to combine them with synchronic activities in a blended learning model as recommended by EHEA guidelines and to shift pre-lab questionnaires to post-lab tests to evaluate the acquisition of competences solely related to procedural and experimental skills and basic principles thereof. In fact, the group of first-year undergraduate students in this study does not favorably scored the e-questionnaires because of the excessive increase of workload and the need to invest time to browse literature in GILEs-type queries and theoretical related tests. We do feel that pre-lab questionnaires might be better received in advanced chemistry subjects in the second to fourth bachelor year, involving laboratory exercises, in which students are already adapted to autonomous learning and acquired skills for fast access to relevant literature via web platforms and databases.

ACKNOWLEDGEMENTS

The authors are grateful to the University of the Balearic Islands for Financial support through the call of innovative educational projects (Convocatòria d'innovació i millora de la qualitat docent de la UIB) within the course 2013-2014.

REFERENCES

[1] Garrison, D.R., Kanuka H. (2004) *Blended learning: Uncovering its transformative potential in higher education*. Internet and Higher Education 7, 95–105.

[2] Garrison, D.R., Vaughan, N.D. (2008), *Blended Learning in Higher Education: Framework, Principles, and Guidelines,* San Francisco, CA: Jossey-Bass.

[3] Brenton, S. (2009). *E-learning-an introduction.* In: F. Heather, S. Ketteridge, and M. Stephanie (Eds.), *A Handbook for teaching and learning in higher education: enhancing academic practice* (3rd Ed.), pp. 85–98, New York: Routledge.

[4] Dabbagh, N., Bannan-Ritland, B. (2005). *Online learning: Concepts, strategies and application.* New Jersey: Pearson Prentice Hall.

[5] Towns, M.H. (2014) . *Guide To Developing High-Quality, Reliable, and Valid Multiple-Choice Assessments.* Journal of Chemical Education, 91, 1426–1431.

[6] Miró, M., Delgado, M.R., Femenia, A., Perelló, J., Tur F. (2011) *Moodle questionnaires: appealing or troublesome tool in teaching/learning general chemistry at universities?* (Eds., Gómez Chova, L.; Martí Belenguer, D.; López Martínez, A.), Proceedings of EDULEARN-11 (International Conference on Education and New Learning Technologies), International Association of Technology, Education and Development (IATED), Barcelona, pp. 1512-1521.

[7] Perelló, J., Tur, F., Femenia, A., Delgado, M.R., Miró, M. (2011) *E-questionnaires as a tool to evaluate the previous knowledge of the students in the bachelor of chemistry* (Eds., Gómez Chova, L.; Martí Belenguer, D.; López Martínez, A.), Proceedings of ICERI-11 (4th International Conference of Education, Research and Innovation), International Association of Technology, Education and Development (IATED); ISBN: 978-84-615-3324-4, Madrid, pp.7082-7088.

[8] Tur, F., Perelló, J., Femenia, A., Miró, M. (2012) *Learning-focused Moodle questionnaires for preparing written exams in a course of general chemistry* (L. Gómez Chova, I. Candel Torres, A. López Martínez), Proceedings of EDULEARN-12 (4th International Conference on Education and New Learning Technologies), International Association of Technology, Education and Development (IATED), ISBN:978-84-615-0441-1, Barcelona, pp.6601-6607.

[9] Miró, M., Perelló, J., Tur, F. (2014) *Ventajas y limitaciones de los Cuestionarios Moodle para aprendizaje mixto en estudios de grado,* Actualidad Analítica, nº 45, pp 7-9, Sociedad Española de Química Analítica, Madrid.

[10] Pinto, G. (2010) *The Bologna Process and Its Impact on University-Level Chemical Education in Europe.* Journal of Chemical Education, 87*,* 1176–1182.

[11] Fakayode, S.O. (2014) *Guided-inquiry laboratory experiments in the analytical chemistry laboratory curriculum,* Analytical and Bioanalytical Chemistry 406, 1267–1271.