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Educational initiatives

Virtual laboratory on biomass for energy generation

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A B S T R A C T

Virtual laboratories (VL) and interactive simulations are excellent approaches for training students to understand technical principles. This can be useful in many fields of science and engineering teaching. For this purpose, we have developed a virtual environment that can simulate real-laboratory operations, effectively enhancing the teaching process with an intuitive and appealing interface. Such software shows the virtual-studio practice characterization of basic biofuel-properties, simulating reality step-by-step. This virtual laboratory has been used by students of the postgraduate master subject on *Biomass for Power Generation*, belonging to the *Master of Distributed Renewable Energy*. The aim of this tool is to help students to study, learn and investigate on their own. The virtual lab is made of a web-based application to complement experimental laboratory training, allowing students to prepare their experimental practices before going to the lab, and to review them at any time afterwards. The computer application exhibits key virtual-lab educational features, like an integrative layout and self-evaluating tests. It allows a personalized and active learning-process, adaptability to teacher's aims and versatility and simplicity, using different multimedia resources. A satisfaction questionnaire was carried out between master degree students to evaluate the usefulness of the VL. Such a tool was positively evaluated, achieving a mean score of 6 out of 7 points. Additionally, the VL efficiency in the learning process showed a final examination main score of 8 out of 10 points. Last but not least, most students considered that the VL promoted learning and personal effort, being an excellent preparatory tool to real experiments.

1. Introduction

Practical teaching sessions (laboratory experiments) are universally recognized as being a key factor of engineering courses, where there is a pressing need for students to integrate their understanding of theory with laboratory practice, throughout the academic year (Barros et al., 2008). Some authors consider that the role of practical work for learning science comes from the importance of introducing students to the world of scientists and engineers in practice (Colwell et al., 2002).

Recently, the importance of the renewable energies (specially in biofuel research such as biodiesel) has grown due to the social and political awareness about ecological and sustainable activities, climate change and global warming, besides regularizations that force their use (Festel et al., 2014). This has also generated an increased interest about such approaches in both research and teaching. However, in energy science, and specifically in biofuel field (such as biodiesel), laboratory implementation as a learning practice should overcome some handicaps. On one hand, it requires both expensive equipment and consumables, besides experienced staff; and on the other hand, a significant laboratory time consumption of around 24 h for biodiesel production and quality analyses. There are also other challenges for making the laboratory practices available to students in today's higher education environment. Among them, it is important to notice that the financial crisis has caused budget reductions in education (Crujeiras and Jimenez-Aleixandre, 2013; Guardiola and Guillen-Royo, 2015). This may entail less laboratory-staff, equipment and consumables

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(Chin et al., 2014; Festel et al., 2014; Moncada et al., 2014). In particular, it is important to remark that the laboratory equipment and reagents are particularly expensive for biodiesel production and quality analyses.

An interesting approach to overcome such difficulties, further complementing both the theory and practice sessions, is to use the new technologies to create virtual environments. Thus, web-based experimental environments can be developed to give students the possibility of working in simulated experimental scenarios, before actually coming to the laboratory. Thus, emerging technologies, such as Internet and mobile devices, among others, may allow achieving new ways of energy-science learning. One of the most popular web-based learning resources is the virtual laboratory (VL). In this way, it is possible the familiarization with the laboratory equipment, consumables and the experimental steps before the real in situ practical sessions (and afterwards, for reviewing purposes). The benefits of this approach include also the reduction of the turnaround times of practical procedure learning, understanding the nature of the experimental work to be carried out in the real laboratory. Likewise, it may facilitate to troubleshoot some issues that may arise during the experimental procedure and generate and discuss the results, as well as helping to answer the teacher's questions in the exercise book.

However, it is recommended to use this kind of computer tool with the appropriate educational methods, to avoid isolation feelings in the students, effectively enhancing motivation (Gilpin et al., 2014) and productivity. Moreover, it should be taken into account that there may not have instant feedback to the student questions and the results are not discussed in a person-to-person way. Thus, some researchers have used e-learning platforms as collaborative environments of VL, by means of asynchronous discussion forums to solve this problem (Barros et al., 2008; Jara et al., 2009, 2012). Therefore, students in this collaborative context should be able to explain their results, justifying the explanations. This method also enables teachers to supervise and help students in their exercises using the VL in a synchronous way. The VL is mostly effective to assist the laboratory-work training of students (Ahmed et al., 2014). It is important to remark that the main role of a VL platform is to allow non-presential learning (like distance-learning), being the first phase in a regular teaching-process, training students for the real laboratory (Chin et al., 2014). In this initial step, students should achieve part of the reasoning skills and knowledge that they may further combine with practical experimental designs and performance in the real laboratory sessions.

Nowadays, there is a huge experience in virtual laboratories applied to different subjects, such as chemistry learning. Thus, some authors have designed an environment for the construction of virtual 3D chemistry experiments for the Internet (Shudayfat et al., 2012). Others have examined the effects of real laboratory *versus* virtual applications on first-course chemistry students, by means of questionnaires and achievement tests (Shudayfat et al., 2012). Results have shown that students prefer conducting experiments in VL to real-laboratory ones, since the former is easier to understand and perform than the latter, with the help of appropriate software applications. On the other hand, the effects of VL chemistry-lessons, based on observations and interviews with students, have been examined (Romli et al., 2001). They concluded that VL software applications are very effective learning environments, with a great potential of performance at a low cost. Other authors (Trindade et al., 2002) have used cognitive-performance assessment tests, achievement tests, written exams and interviews with students to find out the effectiveness of VL. They concluded that students with better levels of spatial skills achieve higher conceptual-learning goals. The methodology based on the chemistry virtual-laboratory has been shown to be reliable, since achieved results by both real- and virtual-laboratory groups were similar (Martinez-Jimenez et al., 2003). Studies based on questionnaires and observations have shown that, despite the fact that VL are not as much effective as real laboratories, they help students to know better the laboratory environment, including equipment and consumables (Dalgarbo, 2004). Similar conclusions were obtained by others, when achievement tests, interviews and observations of students were analyzed (Mercer-Chalmers et al., 2004). Also, it has been found that VL experiments are preferable when there are limited laboratory conditions, like insufficient experimental equipment and consumables (Ergül and Binici, 2006). Thus, most authors consider that virtual environments lead to increased performance and higher learning levels, helping to prepare real practice-sessions and enhancing self-confidence (Schmitt and Parise, 2011; Wang et al., 2011; Herga and Dinevski, 2012).

Although the literature about virtual laboratory in chemistry is plentiful, it is nonexistent for virtual-laboratory biodiesel production. Thus, further research and developments are needed in this area, which has shown an increasing interest and demand from students in the last years.

In this sense, the main goal of this work is to develop a biodiesel production and quality-analysis virtual laboratory. This VL combines the main advantages of standard VL, together with the synchronous-collaborative learning practices, by means of a synchronous discussion forum. Thus, teachers and students may be able to share both theoretical concepts and practical experiences in an e-learning setting using the VL.

2. Materials and methods

An educational project has been developed, based on a Biorefinery Virtual Laboratory (BVL) at the University of Cordoba (Spain). This has been carried out within the Agrifood Campus of International Excellence (ceiA3) <http://www.ceia3.es/en/ceia3/what-is-ceia3>, being funded by the Ministry of Education under the Campus of International Excellence (CEI) initiative. The virtual laboratory has been developed to be used in different Bachelor degrees, including Industrial, Agricultural, Forestry, Computer and Chemical Engineering, Chemistry, Biotechnology and Biology, as well as in the Master of Distributed Renewable Energy, and that of Biotechnology of the University of Manchester (UK) and the Agricultural University of Athens (Greece). Several research groups from the Universities of Cordoba, Huelva, Cadiz (Spain) and the Universities of Birmingham, Manchester (UK) and Athens (Greece) have participated in the web development. To the best of our knowledge, this is the first initiative in Spain for the establishment of a web-based learning platform in the area of biorefinery, in collaboration with other national and international universities.

Fig. 1 shows the developed website, including five virtual-laboratories; namely, analyses of solid biomass, energy applications of biomass, chemical and physical characterization of liquid biofuels, biodiesel production and treatment and utilization of secondary products. Each virtual laboratory contains several experiments, being explained in a step-by-step manner. A specific order is followed, after the theoretical sessions, by means of previous questionnaires, procedures and self-evaluations.

On the other hand, Fig. 2 shows the common structure for each virtual laboratory in the website. All of them were designed to include: i) student evaluation questionnaires to be carried out before they start the practices in the VL. They quiz the knowledge of the students solving puzzles about the different biodiesel-production steps; ii) tutorial to guide the students, supplying information related to the physics and chemistry principles involved, instrumentation and consumables to be used, optimal parameters and video tutorials to help the understanding and handling of the

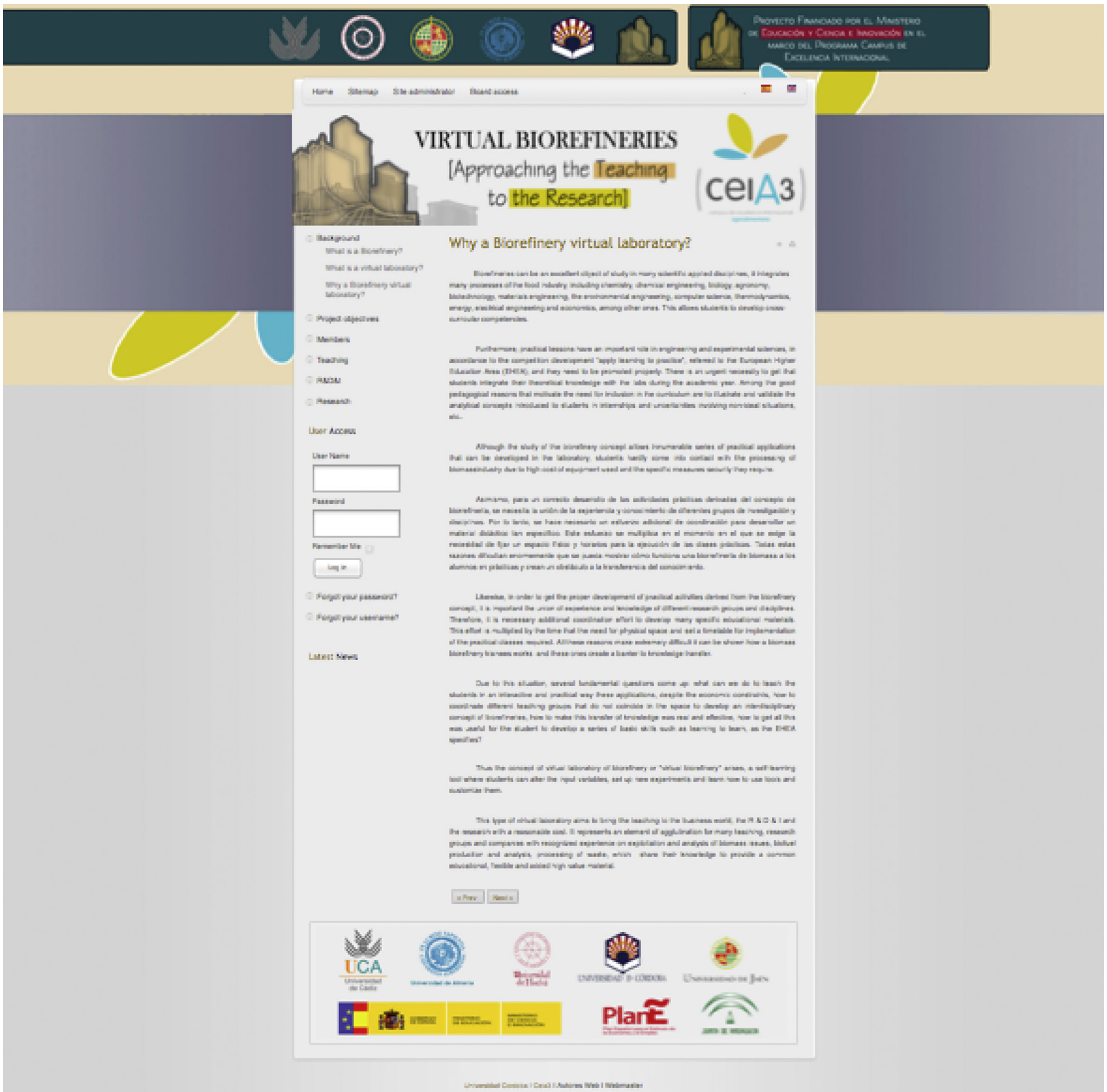

Fig. 1. Website development including five virtual laboratories.

available tools and current law regulations; iii) flow chart of the procedure stages for each VL; iv) photo gallery about the used equipment and consumables; v) expert system to evaluate the student learning process, granting access to the next stage, once the previous one has been successfully passed; vi) video tutorial in which all experiments can be seen, with explanations about the process and the results, the safety precautions and hygienic procedures to be used in the laboratory, among others; and vii) synchronous discussion forum, as a communication tool to improve the interaction with students, thus providing a fast feedback of their knowledge, questions and suggestions. Once they have finished the virtual-practice sessions, there is a self-evaluation

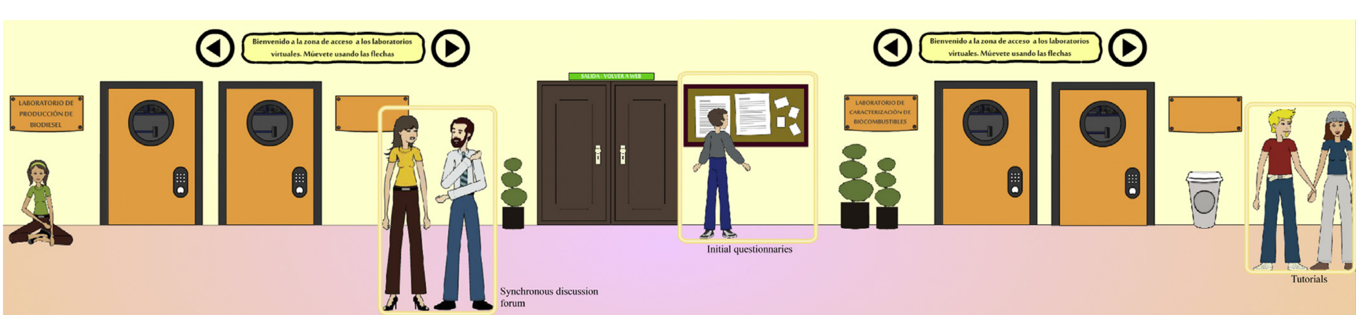

Fig. 2. Common structure of virtual laboratories.

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where the students can check the knowledge acquired and the teachers can receive feedback to further improve the VL.

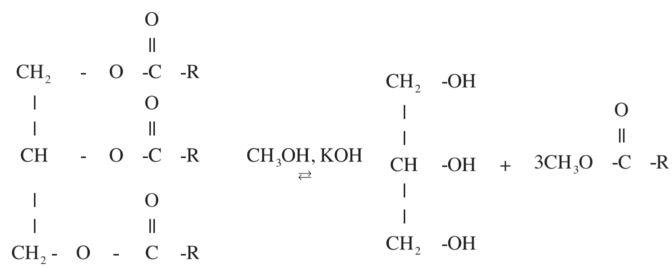
The website was designed for both Intranet and Internet, using a MySQL database and an Apache HTTP server. The implementation of animations and simulations was mainly done in ActionScript programming language in an Adobe Flash 8 environment, to bring better definition to 3D graphics. A web browser and operating system/hardware supporting Flash is available in the University of Cordoba at <http://www.uco.es/docencia/grupos/laboratoriovirtualceia3> and <http://www.biorrefineriavirtualceia3.es/weblaboratoriovirtual> websites.

For the mentioned biorefinery virtual labs, a set of learning topics have been established, as general guidelines: i) overview of the biorefinery processes most appropriate to the biofuel characterization and production; ii) extensive information on instrumentation and hands-on laboratory methods; iii) training young scientists and students in the field of biorefinery, with emphasis on renewable energies; iv) development of software with comprehensive tutorials carried out by experts; v) development of intuitive (easy-to-use) virtual laboratories, so that they may be run by people who do not necessarily have extensive knowledge on the subject or advanced computer skills; vi) improvement of the student-to-student and student-to-teacher communications in a fast and efficient manner; and vii) fast feedback from the students to further improve the VL experience in the future.

2.1. Virtual laboratory of biodiesel production

The development of an effective virtual-laboratory learning-platform requires the deployment of a series of simulations, tools, exercises, applications and conditions. In this way, an appropriate environment can be built, where experimentation, communication and collaboration may be used for the exchange of knowledge and experiences. Thus, the virtual laboratory should include all the necessary functionality to simulate the real processes, as realistically as possible (Abdul-Kader, 2011). Thus, the VL was designed resembling the real laboratory. Graphical animations allow to simulate the reality in the virtual laboratories through their seeming closeness to the look-and-feel of the real ones. Also, they help to remove the complexity of the latter experiments. Thus, the animations can be exploited to reveal information that cannot be easily conveyed via text alone or static illustrations. In our biodiesel virtual laboratory, the development of experiments is based on the use of 3D Flash animations. In this way, detailed procedures such as weighing of raw materials, biodiesel production or safety and hygiene protocols (that are crucial to achieve good results in the experiments) can be properly illustrated.

To perform the real physical experiments in biodiesel production, a set of laboratory equipment and consumables like vegetable oils, catalysts and alcohols were required. To create a virtual laboratory of such experiments, it was necessary to substitute the real process, describing biodiesel production in a clear step-by-step way. In this sense, biodiesel is usually produced from many vegetable or animal lipids (oils and fats), through the transesterification of large branched triglycerides (TG) into smaller straight-chain molecules of esters. The process of transesterification can be carried out by means of biochemical catalytic methods, like alkaline or acid, homogeneous or heterogeneous catalysts (Pinzi et al., 2014), as well as uncatalyzed processes with supercritical methanol (Demirbas, 2003). Not surprisingly, the transesterification can by enhanced by energy-sources like microwaves (Azcan and Danisman, 2008) or ultrasounds (Sáez-Bastante et al., 2014), which effectively increase the molecule vibrations, and thus their effective collisions to react. The conventional and traditional methodology for the production of biodiesel involves the alkaline homogeneous transesterification of oils and fats at relatively mild temperatures (25–65 °C). Nowadays, this transesterification process has a high acceptance by producers and costumers, being the most economically viable. When the alcohol used is methanol, the process is called methanolysis. It consists on three stepwise-reactions, with the intermediate formation of diglycerides (DG) and monoglycerides (MG), resulting in the production of three moles of methyl esters (ME) and one mole of glycerol (GL) per triglyceride mole, as the following overall reaction shows (Meher et al., 2006). Thus, triglyceride plus methanol and catalysts (sodium or potassium hydroxide) generates propanetriol (glycerol or glycerin), plus the methyl esters of the fatty acids, as shown in eq. (a).



(a)

The stepwise reactions are shown in eq. (b):

$$
\begin{aligned}
&TG + CH_3OH \underset{\leftarrow}{\rightarrow} DG + RCO_2CH_3 \\
&DG + CH_3OH \underset{\leftarrow}{\rightarrow} MG + RCO_2CH_3 \\
&MG + CH_3OH \underset{\leftarrow}{\rightarrow} RCO_2CH_3 + GL
\end{aligned}
\qquad (b)
$$

This experimental method consist of three main phases:

1) *Mixing*. First, the oil/fat should be selected to produce biodiesel through transesterification. For instance, oil (100 g) is poured into an Erlenmeyer flask and heated at reaction temperature, stirring at 1100 rpm during the reaction time. When the temperature of oil reaches the reaction temperature, it is mixed with the catalyst (KOH) and alcohol (methanol). This is when reaction starts. The obtained product is segregated in a decantation funnel for around 24 h (or centrifuged for 10 min). In this way, separation of two phases (upper less-dense layer corresponds to biodiesel, whereas the lower denser one is made of glycerol and different impurities) should be displayed here. The separation of these phases can be accomplished using a pipette.
2) *Washing*. The produced biodiesel should be washed with distilled water, in order to remove the hydrophilic impurities. Then, the water is separated from biodiesel by decantation.
3) *Drying*. Anhydrous sodium sulfate is added to the biodiesel for removing the residual water. Finally, this mix should be ceramic-filtered with a funnel. The expected yield is around 97 g of biodiesel for each 100 g of starting oil/fat.

Therefore, the first document of the virtual laboratory that is displayed to the students is the scheme of the biodiesel production. It shows how to operate such virtual laboratory, allowing to carry out all steps with the help of a virtual-laboratory assistant called “Azahara” (see Fig. 3). Then, the students have to complete the scheme in a first questionnaire, as shown in Fig. 4. Completing the scheme helps the students to understand the general process of biodiesel production, which is primordial in the real laboratory. Moreover, during the practical exercises, an expert system

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Fig. 3. Virtual assistant (*Azahara*).

evaluates the knowledge of the students in their learning process, by means of different questions about the virtual equipment and consumables, techniques and results that are expected to achieve. Thus, before starting the practical virtual-exercise, the laboratory equipment and consumables that will be used is detailed as both 3-D models and explanatory legends (see Fig. 5). It is important to remark that previous work in real laboratory have shown that the previous knowledge of laboratory equipment and consumables helps the students becoming familiar with them, thus reinforcing safety precautions and reducing the time spent to achieve the practical goals in the real laboratory. Also, a step-by-step video tutorial of biodiesel production is available from the tool-bar menu (see Fig. 6), which has been found to be an excellent teaching tool. In fact, different video tutorials about the biodiesel production phases can be played. Other additional resources about the laboratory equipment, consumables and procedures used in the VL practice sessions are shown in the picture gallery.

The collaborative environment is achieved with the help of a synchronous discussion forum. Since the beginning, all the students and teacher are connected via the forum available in the website. There, the students may interact between them and the teacher to ask and answer questions about the practical exercises and the achieved results. Finally, the students have to answer two questionnaires: a self-evaluation, where they should prove their knowledge, as well as a feedback evaluation about their virtual-laboratory experience (Figs. 7 and 8).

2.2. Teaching experience and methodology

The virtual laboratory website has been used by students of the *Biomass for Energy Generation* subject, corresponding to the Master of *Distributed Renewable Energies* at the University of Cordoba from the 2011/12 academic term. A total of 30 students participated in this educational research project, which were distributed in small groups in order to carry out a personalized instruction. The followed educational methodology is similar to that of other research projects using and evaluating VL (Dalgarno et al., 2009; Jara et al., 2009). In this sense, the case selection and criteria were based on two points: the use of both practical lessons at the University and practical lesson through the Internet. After the starting term, it has been also included in the courses of the other Universities participating in this project. The laboratory sessions are a necessary part of the module designed for the master students. As mentioned before, the goal is to introduce the students to the principles of energy generation, such as biodiesel production, characterization and properties, among others.

This subject consists of four two-hour practical sessions, scheduled for four consecutive weeks. In the first week, the students are introduced to the laboratory equipment and consumables. The main objectives of this first session are: i) to acquaint with laboratory elements and process concepts; and ii) to know all safety and hygienic protocols that should be followed during the real practical-experimentation.

During the second week, the students are introduced to the biodiesel production through transesterification. The aim of such experiments is to show the process of biodiesel production step-by-step, using the selected oil/fat. In the third week, the students are familiarized with biodiesel properties. Its aim is to analyze the different chemical and physical properties of biodiesel from the last session, such as cetane number, viscosity, bulk modulus, iodine number and oxygen content, among others. In the last week of real practical-sessions, the students are acquainted with the analysis of exhaust emissions of engines fuelled with the biodiesel produced and analyzed in the previous session. The main aim is to measure exhaust emissions, such as nitrogen oxides (NO_X), carbon dioxide (CO_2), sulfur and oxygen, among others. Likewise, to correlate the results with the chemical and physical properties obtained in the third practical session.

All students were prepared for the real practical-sessions by using the virtual-laboratory software in a computer-room session. Thus, the students were divided into appropriate session groups. They had virtual practical-sessions the same week in the laboratory. As mentioned above, the laboratory teaching extends over four weeks: from the second academic week until the fifth one of the second semester. Thus, in week one, an introductory lecture was organized in a classroom for all students, describing the experiments to be carried out. In the first virtual practical-session, a pre-laboratory preparation session was organized, during which the students played with the virtual-laboratory software in the computer room, following the same procedure as if they were using the real lab (working in groups) and using the forum. At the end of this session, all students filled a satisfaction questionnaire about

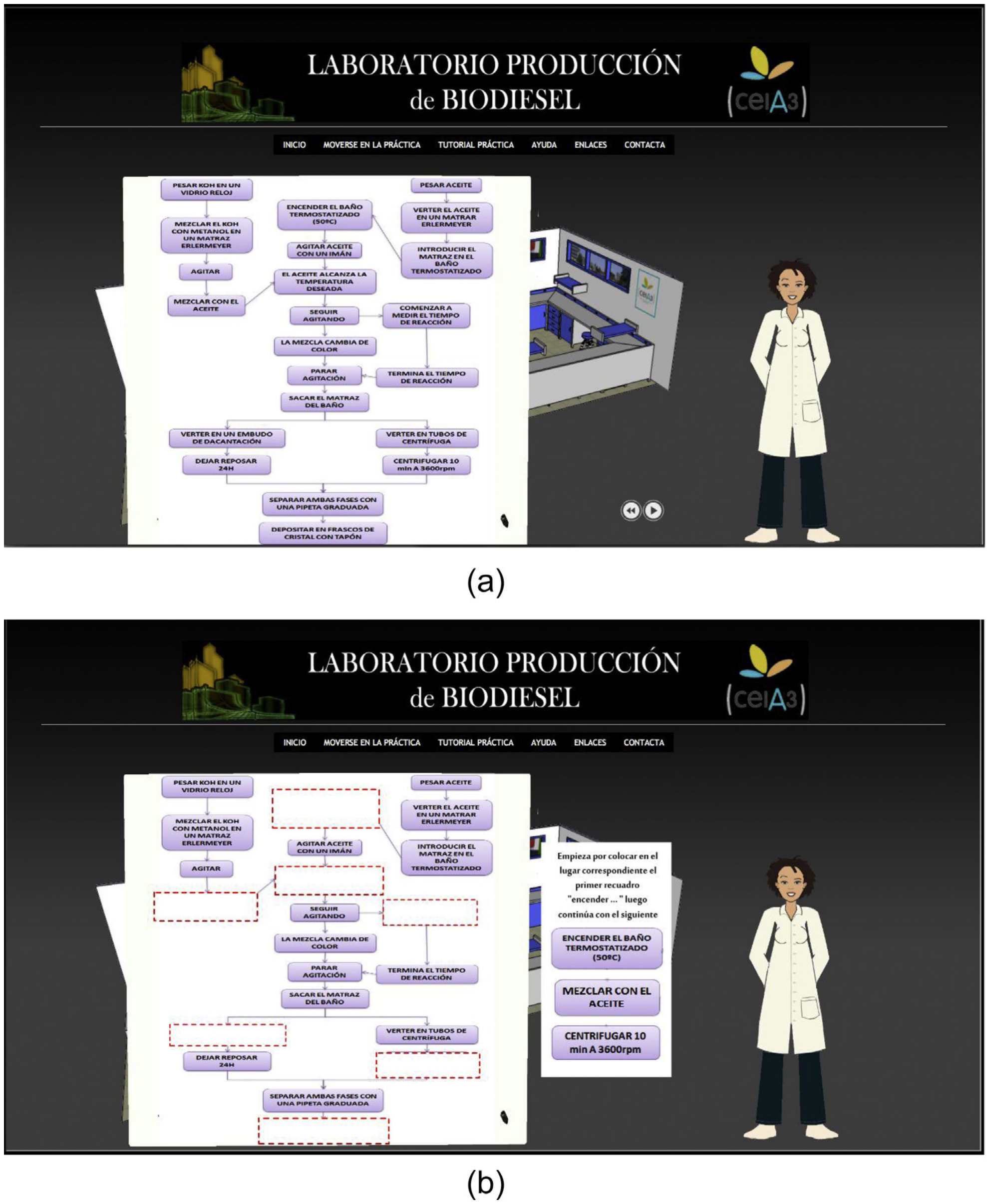

Fig. 4. First questionnaire: a) complete scheme of biodiesel production; and b) partial scheme of biodiesel production to be completed by students.

the VL. The purpose of this feedback was to evaluate the usefulness of the system, since it is known that the student satisfaction and motivation are key success factors (Levy, 2007; Verdu et al., 2012) and to further improve the platform. Thus, the questionnaire items focused on five main topics: I1 – help resources; I2 – ease-of-use and interface environment assessment; I3 – motivation encouragement; I4 – learning promotion; and I5 – adequate theory content.

Furthermore, a study about the VL efficiency in the learning process has been made. For this reason, it was evaluated if the proposed goals for each one of the practices have been accomplished. In consequence, it was necessary to check the scores obtained by the students after each session, and the virtual practice influence in the final results, including real practices plus theory exams of the subject. In order to analyze the evaluation results for each of the practice objectives, the partial marks assigned to the students in the different groups were taken and, for each one, four categories or levels of learning were established, according to the following categories: I corresponded to very low marks (deficient learning), II meant average marks (fair or semi-acceptable learning), III were high marks (good learning level) and IV corresponded to very-high marks (very-good learning level).

3. Results and discussion

Table 1 shows the questionnaire filled by the master-degree students since the 2011/2012 term. Responses were rated on a seven-point Likert scale, ranging from strongly disagree (1) to strongly agree (7). In addition, the students were asked about the advantages and drawbacks of the use of the VL, by means of free-answer questions, expressing their comments and suggestions about it. In general terms, the survey showed that the experience was positively evaluated by students, the mean score for all questions being around 6 points (strongly agree).

In relation to the questions about item I1, the variety in advice and suggestions (Q1) and supplementary-help information (Q5)

Fig. 5. 3-D models and laboratory resources.

results indicate that the students' level of satisfaction with the VL was 5.92 and 5.80, respectively. This further highlights the importance of an appropriate support using the *Azahara* virtual assistant and the video tutorials. Indeed, the *Azahara* assistant support through VL, as well as the use of video tutorials showing the complete process of biodiesel production, were specially appreciated by the students. In relation to the ease-of-use (I2), most of the students considered that the level of clarity (Q2), the degree of VL ease-of-use (Q9) and the relationships between the structure and the ease-of-use (Q10) were reasonable, giving a mean score around 6.22. This may be due to the use of 3D animations and the similarities to the real laboratory. Also, the first initial questionnaire about the general diagram of biodiesel production gives a comprehensive idea of the structure and steps that should be followed in the VL.

With regard to the motivation encouragement (I3), the students strongly agreed that the VL helps to develop the creativity (Q6) and improves the self-confidence (Q4). Again, it could be due to the use

Fig. 6. Video tutorial of biodiesel production.

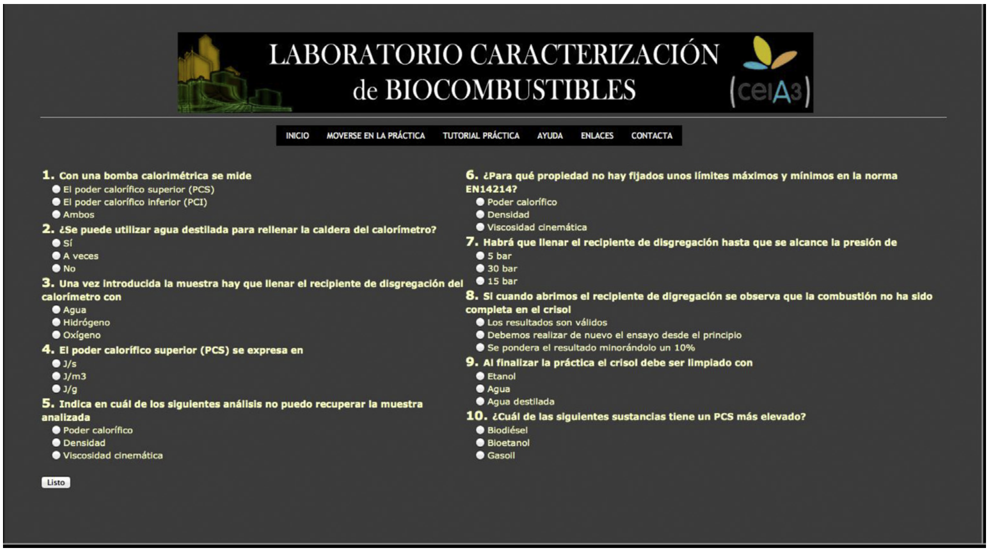

Fig. 7. Self-evaluation questionnaire.

of 3D animations and the video tutorial, as they help to improve the understanding of the work in the real laboratory, including the safety precautions. In addition, most of the students considered that the VL promotes learning and personal effort (I4) where 100% choose to agree, strongly agree or very-strongly agree. This really highlights the importance of the VL as an introductory training to real laboratories, since students are motivated to carry-out the real practices in the real laboratories. As mentioned above, the use of video tutorials, the initial questionnaire and the help of the *Azahara* assistant are very useful tools introducing the real laboratory to the students. Also, the students have been very positive when evaluating the theory contents of the VL (I5). All agreed that the level of information was good at the website of the VL (Q3). In relation to the assessment of the guidelines (Q11), only 5% were undecided in relation to the importance of the text in the VL (Q7) and the assessment of the video-tutorial (Q12). In relation to this, it is important to keep the available contents up-to-date and also practically-oriented. The standard deviation was very similar for all topics, showing a low data dispersion in relation to the mean score.

Table 2 shows the score frequency obtained by the students for each teaching level of the virtual-laboratory practices, as well as for the final evaluation. Furthermore, the main score and standard deviation have been displayed. In this table, the higher frequencies correspond to the good and very good scores, with the deficient level showing no hits. Besides, the mean score for the final qualification was 8.021 out of 10, with a standard deviation of 1.13. This was due to one student bias, which never attended the VL practice. The final score of such student was acceptable, but caused a decrease of the mean and a considerable increase in the deviation for the VL scores.

Taken as a whole, the above data does corroborate that the use of VL enhances the understanding and learning experience. This finding is consistent with previous reports on virtual laboratory effectiveness (Klahr et al., 2007; Zacharia and Constantinou, 2008).

Fig. 8. Feedback from student questionnaire about web server.

Table 1
Master-degree student-questionnaire results for 2011/12.

Topic	Statement	Very strongly disagree (1) (%)	Strongly disagree (2) (%)	Disagree (3) (%)	Undecided (4) (%)	Agree (5) (%)	Strongly agree (6) (%)	Very strongly agree (7) (%)	Mean score[a] $\bar{x} = \frac{\sum_{i=1}^{n} x_i f_i}{n}$	Standard deviation $\sigma = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2 f_i}{n}}$
I1	Q1. The advice and suggestions are useful	0	0	0	0	48	12	40	5.92	0.21
I1	Q5. The supplementary information is helpful	0	0	0	5	35	35	25	5.80	0.17
I2	Q2. The experiments are clear and organized	0	0	0	5	17	20	58	6.31	0.21
I2	Q9. The VL is easy to use	0	0	0	10	20	8	62	6.22	0.22
I2	Q10. The structure enhances the ease-of-use	0	0	0	0	28	22	50	6.22	0.20
I3	Q4. The VL improves the self-confidence and assurance	0	0	0	5	30	10	55	6.15	0.21
I3	Q6. The VL boosts creativity	0	0	0	0	22	30	48	6.26	0.19
I4	Q8. The VL improves the personal effort	0	0	0	0	28	32	40	6.12	0.18
I5	Q3. The VL information in the website is adequate	0	0	0	0	28	24	48	6.20	0.19
I5	Q7. The VL text is adequate	0	0	0	5	35	12	48	6.03	0.19
I5	Q11. The guidelines are appropriate	0	0	0	0	30	22	48	6.18	0.19
I5	Q12. The video-tutorials are appropriate	0	0	0	5	20	30	45	6.15	0.18

[a] Mean score range from 1 to 7, where f is frequency, x is the matching score, n is the number of samples.

Table 2
Master-degree student-practice results for 2012/13 (virtual laboratory).

	Not attending	Deficient	Semi-acceptable	Good	Very good	Mean score[a]	Standard deviation[b]
Practice 1	8.3	0	0	55.5	36.2	8.3	0.73
Practice 2	8.3	0	2.7	75.1	13.9	7.94	0.66
Practice 3	8.3	0	2.7	41.3	47.3	8.24	1.2
Practice 4	8.3	0	8.3	72.3	11.1	7.76	0.79
Final Evaluation	5.56	0	13.89	52.78	27.78	8.021	1.13

[a] Mean score: $\bar{x} = \frac{\sum_{i=1}^{n} x_i f_i}{n}$, where f is frequency, x is the matching score, n is the number of samples.

[b] Standard deviation: $\sigma = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2 f_i}{n}}$.

Furthermore and interestingly, the obtained results support the conclusion that the students can concentrate better on task-relevant aspects in the virtual laboratory *versus* the real one, since in the former they are not distracted by external factors that may be present in the latter (Chien et al., 2015). This highlights the special effectiveness of the virtual laboratory as an introductory lesson before entering the real laboratory. Furthermore, the academic implications of video tutorials that we have found are in agreement with Olympiou et al. (2013). Thus, gaining such prior knowledge positively influences mental modeling for a later better conceptual understanding in the real world, which is indeed one key aspect of virtual environments for teaching purposes.

4. Conclusions and future work

This work has focused on showing the Virtual Laboratory (VL) of Biodiesel Production used in the learning of the subject *Biomass for Energy Generation*. On one hand, the VL provides the students the necessary tools for developing practical experiments in a virtual environment, with the main advantages of the permanent availability of the virtual equipment and consumables for all students, and the student safety in the virtual environment. On the other hand, the VL allows students to access the virtual tools as many times as required, without the time or timetable constraints of the real-laboratory experiments. Additionally, virtual teaching can be carried out off-site, anywhere in the world with Internet access (and even without it when used offline), without requiring a physical presence in the real laboratory. This is an obvious advantage for distance learning.

The developed software is compact, intuitive, friendly and constitutes an effective new tool for introducing students to the biodiesel production and practice study. Computer simulations of fundamental concepts, devices and other tools are an important part of this software. The students play an active role in the simulations, by setting up and changing the experimental setup, according to the tasks to be solved.

The usefulness of the VL has been further evaluated by the master degree students, by means of a satisfaction questionnaire. Furthermore, a study about the VL efficiency in the learning process has been carried out. Thus, it has been evaluated if the proposed goals for each practice task have been properly accomplished. The questionnaire results showed that the VL was positively evaluated. The evaluation results of the virtual-laboratory practices showed a good teaching level.

In summary, the students have greatly appreciated the VL experiences, increasing their motivation to learn biodiesel production. Finally, the English version of this software and more effective evaluations by means of both questionnaires and control groups are currently under development.

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