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ISLE: An Integrated Self-Learning system of Electronics Using a Virtual Laboratory as a Self-Assessment Tool*

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Students currently learn theoretical concepts about Electronics in class sessions and then go on to work in a laboratory. Usually, when they arrive to the laboratory they have insufficient knowledge about the relation between theory and practice and also measurement instruments operation. As a result, component damage is common during laboratory sessions. This paper introduces ISLE (Integrated Self-Learning System of Electronics), an integrated learning system for students to use as a self-assessment tool. The objective is to improve the students' knowledge about the relations between theory and practice and to prepare them to work efficiently in the laboratory. ISLE combines a hypermedia book with a virtual laboratory and a multimedia test tool. It follows the constructivist theory and constitutes an interactive computer-based complex tool enhancing competence based learning. The system was tested in a first course on Electronics. Four groups of students took part: two groups used ISLE and the other two groups did not. Having observed some differences in the means of both groups, a statistical comparison was conducted using SPSS. To compare the averages, a variance analysis (ANOVA for one factor) was carried out using Tukey contrast. The observed differences are significant.

Keywords: self-learning system; virtual lab; self-assessment

1. Introduction

The high degree of maturity attained by Information and Communication Technologies (henceforth ICTs) provides opportunities to develop new ways of running the higher education process and improving its quality. This challenge involves carrying out applied research and technological development activities to devise new educational products to be used both in formal higher education and in continuous training to raise the educational process quality, so improving students' self-study capabilities, self-assessment of their knowledge and the efficiency of the teaching/learning process involving both student and teacher. This challenge is particularly important in teaching engineering subjects because the complexity attained by the majority of technologies means that modern society requires engineers who are capable of critical thinking, analysing and synthesising information and working in a team to develop new products that solve problems emerging from social, political and economic activities.

Over the last few years, the engineering teaching/learning process has moved into an environment that encourages the development of new educational models and methodologies. The factors within this environment include the following.

1. Social changes linked to globalisation drive educational approaches such as the European Higher Education Area (EHEA), setting new guidelines with the aim of guaranteeing that students acquire skills throughout their studies, enabling them to work at their profession anywhere in Europe.
2. Different organisations including many engineering institutions and associations [1–3] are concerned with current engineering teaching quality and have published accreditation standards and other documents. They all agree that it is only possible to develop and learn engineering skills if training involves a student-centred process of self-regulated learning and domain knowledge construction [4], making lab experiments essential [5]. For this reason, they recommend that the engineering education process, as well as providing students with the right theoretical knowledge, must involve demonstrating in practice the accuracy of the theories put

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forward, and transferring design rules enabling them to develop new systems and applications.
3. The development of the aforementioned ICTs might accelerate convergence between traditional classroom education and distance and online education, providing several possibilities to improve the teaching–learning process, which might be used to our best advantage.
4. Virtual laboratories have been widely used to support the learning of theoretical concepts. However, current virtual labs do not provide students with information concerning their level of practical achievements [6, 7]. Using a self-assessment tool combined with a virtual laboratory, students can learn from their mistakes and get a better preparation to enter the real laboratory [8].

2. Constructivist methodology for technology learning

It can be deduced from the previous section that there is a need to create new forms for the teaching–learning process [9–12] because traditional systems, fundamentally based on lectures in many countries, do not guarantee achieving the skills that are required to learn about the different technologies generally characterised by being made up of a set of interrelated concepts. Consequently, different authors have coined the term Complex Technologies [13] and have demonstrated that several problems arise when learning about these topics, including a lack of effective pedagogic methodologies, a lack of attractive resources available for the students and the fact that these resources often do not adapt to the students' different styles of learning and levels of knowledge [14, 15].

These new approaches focus on student performance and guide them towards active learning, one of the basic principles of constructivism [16, 17]. This implies that students must complete different learning activities, assuming responsibilities and committing to what they do, how they do it and the results achieved. They should also develop learning autonomy, critical thinking, professional skills and self-assessment capabilities.

It is within this context that different experts in education, some of whom are also engineering teachers and systems designers in different areas of Technology, who are concerned about teaching quality, have pointed out [18–20] that using ICTs provides comparative advantages, such as: it promotes teaching from the specific to the general, presents the concepts in a proper didactic sequence, encourages a constructivist approach that fosters self-learning, and provides demonstrations and visual illustrations that can achieve the right balance between abstract and concrete concepts.

Alternately, learning assessment should focus on real life situations involving significant and relevant complex problems that require a much wider acquisition of knowledge, skills and attitudes than can be demonstrated through traditional exams. A constructivist environment demands resources, including motivation, as important factors in the assessment procedure [21]. By using the methodology that is proposed in this paper, this process is enhanced and improved, helping to achieve a methodological and conceptual change for students and teachers and change their attitudes for the better.

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3. Technological systems for learning about technology

As a consequence of the circumstances described in the previous sections, many institutions attempt to innovate in the field of engineering learning by experimenting directly on the students in the classroom with different teaching methodologies and by using ICTs as learning tools. However, among the results obtained, it is worth highlighting some facts.

1. Although virtual learning platforms [22] are used in a generalised way, many educational centres still use them as pegs to hang class notes on, so that in terms of organisation, students have the documents that they usually collected from the photocopying facilities neatly arranged on the Web.
2. The author tools do not facilitate intellectual property protection for the systems produced with them, and more specific design and simulation programs on several branches of engineering are not particularly designed for teaching purposes.
3. Virtual labs can be used so that students come to the real lab ready to work with a high level of autonomy. If virtual experiments are designed properly, they can make the students feel as though they are taking an active role in their learning. The virtual lab concept is not standar-

dised; this label is assigned to systems with very different features [23]. In practice, we can consider two major categories of virtual labs: simulated labs [24] and remote access to real labs [25]. To be really efficient, virtual simulated labs should imitate the students' real work environment as much as possible, both in appearance and in functional features, and so they must comprise a set of lab experiments including interactive simulation instruments that can be used from the student's own computer or over the Internet.

4. There are evaluation tools in virtual environments that automate the assessment process because they make it easier to collect data, grade the students and return information to them [26–28]. Some studies also offer guides to develop the assessment in virtual environments and others demonstrate the advantages offered by this type of evaluation to automate and provide feedback for the teaching–learning process [29–31]. Self-assessment is usually carried out with questionnaires comprising a set of multiple choice questions or true/false questions [32, 33]. Whilst this is a valid approach, it is difficult to assess technological knowledge properly if used in isolation, because it is not possible to measure its level through questionnaires alone.

In the area of engineering teaching that we deal with, an ideal method would involve the student answering each of the formulated questions, and then going to the real lab to carry out the practical assembly of the circuit featured in the question, thereby checking that the supplied answer is valid. However, this process requires a great deal of time and material resources. Also if the student discovers in the lab that his/her answer is wrong, he/she has to search among a mass of physical assemblies and notes for the reason for the problem. This is where ICTs provide the possibility of developing new tools that help to overcome these difficulties.

To guarantee the success of incorporating ICTs into the technology teaching–learning process it is necessary to review the assessment focus and try to raise the skills level using questionnaires implemented with multimedia resources.

The situation described above led the authors to develop the concept of Integrated Self-Learning system of Technology described below.

4. A model for an integrated self-learning system of technology

An Integrated Self-Learning system of Technology (henceforth ISLT) is an education system that, as its name suggests, is aimed to support self-learning. It includes a hypermedia book, a virtual lab, and a self-assessment tool combining suitable questionnaires with virtual lab experiments, thereby giving a technology education system that is characterised by making it easy for students to experiment with theoretical concepts, carrying out authentic and significant tasks and acquiring the capability to organise and plan their work autonomously.

4.1 Interactive hypermedia book

In this hypermedia system, each concept is linked through active words with the concepts on which it is based, plus any other being used, in turn, to constitute more complex concepts [13]. Furthermore, this distinguishes it from a traditional book by including spoken explanations and videos.

The hypermedia book that forms part of the ISLT is associated with a set of experiments making up a virtual lab. They not only provide the students with a better understanding of the concepts but also prepare them for using a real lab properly. Each important concept, about which not only theoretical but also practical knowledge must be acquired, is associated with an experiment.

The hypermedia book uses concept maps [34] to present the reader with a comprehensive view of the relationship between different concepts, thereby providing access to them in visual form. Each basic concept is associated with at least one simple virtual laboratory experiment and the complex concepts are associated with experiments combining the adequate simple experiments.

4.2 Virtual lab

The ISLT virtual lab is a computer-based tool comprising a set of virtual experiments, bearing the following attributes.

- It has a user friendly interface enabling first-year students to use system resources intuitively, in contrast with most commercial simulators on the market, such as some used in Electronics [35, 36] or based on them [37, 38]. It uses simulated measuring instruments whose functional features are similar to those of real instruments.
- It includes interactive pedagogic simulations relating theoretical and practical concepts and requiring so few computer resources that they can be included in any other program.
- It includes virtual 'destructive' essays that—for safety or economic reasons—cannot be carried out in a real lab, thereby showing students the negative consequences of incorrect manipulation of real elements.

4.3 Self-assessment tool

The self-assessment tool implements a constructivist perspective of assessing skills [39]. It comprises a set of questionnaires, each of which is associated with an experiment from the virtual lab. Questions are organised into different levels of difficulty, providing the student with qualitative explanations and quantitative reports in the form of numerical grading at all times.

5. Description of ISLE

Figure 1 showed a block diagram of an ISLT. As indicated in the previous section, it comprises a hypermedia book, a virtual lab including a set of experiments and a multimedia test tool. These last two elements constitute the self-assessment tool.

In order to validate the practical usefulness of the ISLT model described in the previous section, an ISLE (Integrated Self-Learning system of Electronics) has been developed.

The target students for this system are studying Electronic Technology within an engineering degree. With ISLE, students assume active roles in their learning processes, because they not only study the theory and the problems for the subject at hand, but they also self-assess and may use the self-assessment results to decide if they need to go back and start the process again. Finally, the students attend the real lab with the right confidence and motivation.

ISLE three subsystems are described below.

5.1 ISLE hypermedia book

The ISLE hypermedia book is characterised by the consequent use of concept maps to show students the relationships between the different concepts and make it easy for them to move from one to another. In addition, the different concepts are described with the appropriate images (graphic schematics and representations) showing their behaviour. Each basic concept is associated with one or more experiments from the virtual lab that the student must carry out after studying it.

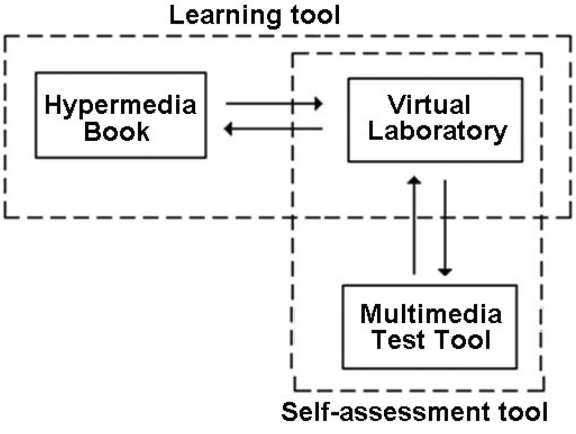


Fig. 1. Block diagram of an integrated system for self-learning of Technology (ISLT).

5.2 ISLE virtual lab

The ISLE virtual lab comprises a set of experiments [40] sharing a common user interface, including generating instruments, measurement instruments, input and output elements and the electronic circuit whose operation is checked, as represented in Fig. 2.

The virtual lab user can carry out different experiments, acting freely on the different elements they comprise, thereby checking that they work properly. Furthermore, for the virtual lab to be a self-learning tool, each experiment contains one or more activities guiding the users on the actions that they must complete to be able to understand fully how the studied circuit works.

The circuit checked by the experiment is represented on the screen by means of a diagram that is identical to the one used in the hypermedia book.

The virtual instruments behave almost identically to actual instruments used in the lab, whether or not they are based on a computer, and they allow the student to visualise and measure the signals that are present at the right points on the circuit.

Figure 3 shows the user interface for an Analogue Electronics experiment using a power source, a signal generator and an oscilloscope. This experiment describes how a non-inverting operational amplifier works and the effect of saturation on it.

The virtual laboratory was programmed in Visual Basic 6. Depending on the experiment, the user can select the diode, transistor or operational amplifier to be used. The circuit is already drawn in advance with the wiring. In the experiments, the user must set up the instruments as he/she would do in a real lab, selecting the type and frequency of the wave, working through the appropriate buttons and changing the values of resistors, capacitors or components to observe its effect on the output. When exceeding the maximum values, the user is warned by notices, or a flame indicating the destruction of the component.

The virtual lab installation procedure is very simple. Depending on the version of the Windows

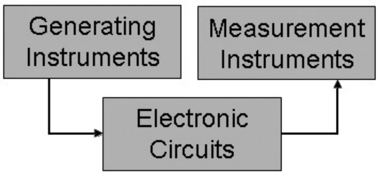


Fig. 2. ISLE Virtual laboratory graphic user interface including generating and measurement instruments.

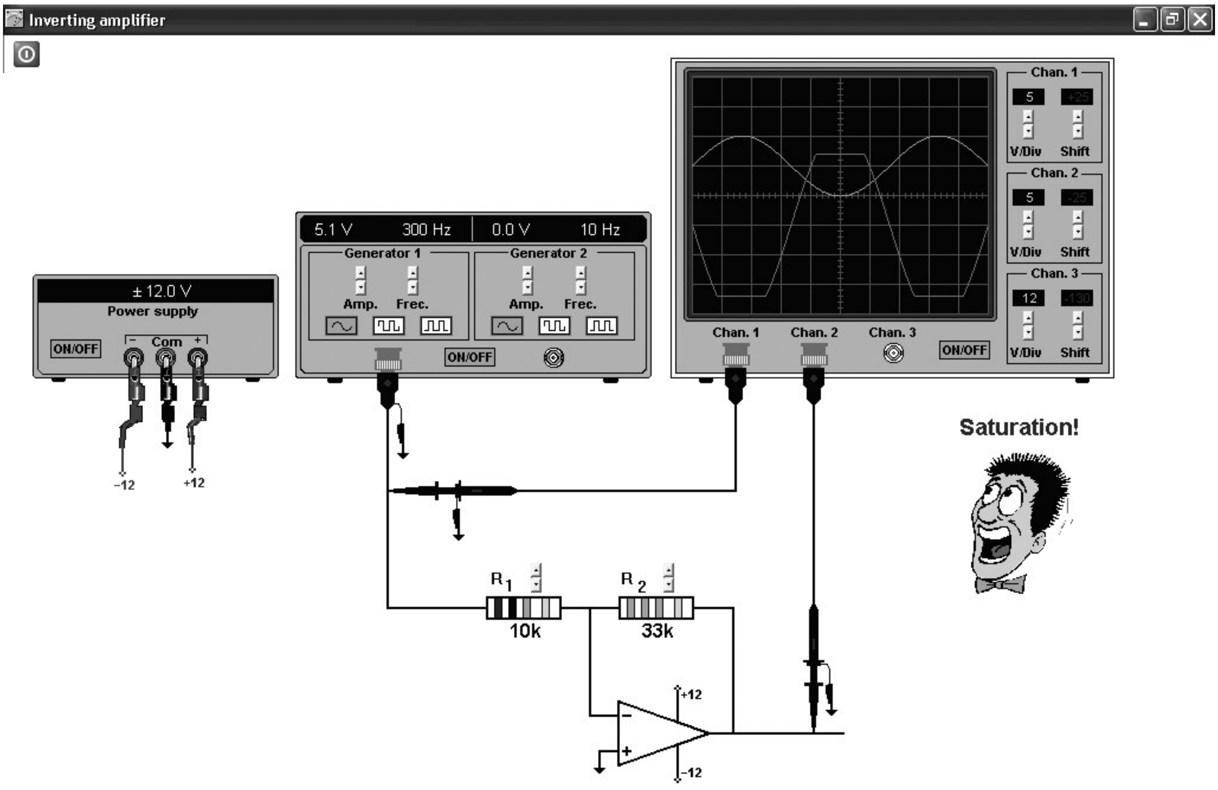


Fig. 3. Example of virtual lab experiment verifying the inverting amplifier behavior.

operating system, the user must install a set of DLLs (Windows XP), which occupy about 3 MB. For later versions of the Windows operating system, there is no need to install any DLL. Each experiments uses between 100 and 300 kB of hard disk space, depending on the type of experiment.

5.3 ISLE self-assessment tool

After finishing the study of each chapter in the ISLE hypermedia book, the student can complete the self-assessment test consisting of a set of multiple choice questions. This process is depicted in flow diagram form in Fig. 4. Beginning the self-assessment session, the system displays the first question, asking the student for an answer. Once he/she has selected a specific answer, the system deploys the experiment involving the circuit under analysis to conduct it and ascertain whether his/her answer is correct or not, or if he/she doesn't know. In the last case, the system gives an explanation and it directs the student to read the hypermedia book. If the answer was yes or no the system executes the checking process to detect if the answer was right or wrong. If the answer was wrong, the system also gives the explanation. Finally the system displays a new question if it was not the last question.

It should be highlighted that the ISLE self-assessment tool does not tell the students directly whether their answer is correct or not, but leads them to

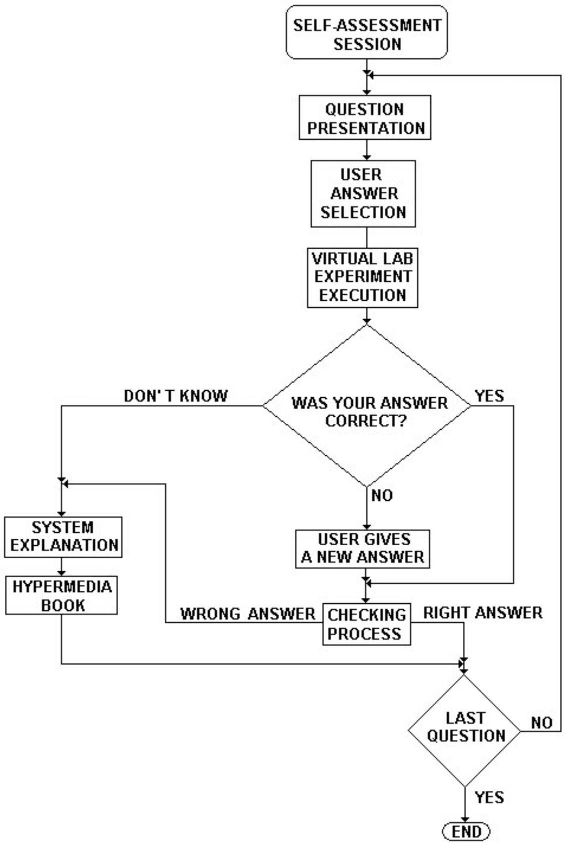


Fig. 4. Self-assessment tool flow diagram.

discover the truth for themselves by performing a suitable experiment.

There is a double assessment: first in the question that is made, and second in the experiment performed. This tool has been created using a methodology that assesses skills, where the links to the virtual lab serve to complete and increase the level of knowledge [41, 42] Students are constantly aware of their level of learning, as they are also asked about it. This is available to students as a part of ISLE and is supported by the Moodle Learning Management System, so that students learn autonomously.

6. ISLE Assessment on the transistor topic

ISLE was tested with the topic of transistors in the Analogue Electronics course at the San Sebastian Polytechnic University School of the Basque Country, in Spain during the 2007–08, 2008–09 and 2009–2010 academic years.

To ascertain the impact of ISLE on the teaching–learning process of the above-mentioned subject, the following three aspects have been taken into account:

1. The students' academic results, by means of comparing students' results from 2005–06 and 2006–07 (control groups), where ISLE was not used, with students from 2007–08 and 2008–09 (experimental groups) where it was used.
2. The results of implementing ISLE controlled assessment modules in a computer classroom for the 2009–10 academic year.
3. The students' opinions via a survey about the level of satisfaction using the system.

The results are presented below, along with the analysis of these three aspects. The Transistor topic selected as a sample for this study was taken from the Analogue Electronics course.

A simple example of assessment on how transistors work is shown in Figs 5 and 6. Figure 5 shows the question already answered on the link to the virtual lab for an amplifier circuit using just one transistor. For the question 'If the transistor temperature increases . . .' the student has chosen the first of the four available options, namely 'The bias current increases and the transistor is destroyed'. This question is aimed to ascertain whether the student has understood the effect of temperature on transistors.

Once the student has chosen an answer, the program launches the virtual lab experiment corresponding to the circuit under analysis as represented in the figure. The students can interact with the experiment by activating the switches for the instruments and bringing the heat source closer to the transistor. Then the students can visualise the circuit operating conditions on the instruments and check whether their answers are correct or not, as they would do in an actual lab work.

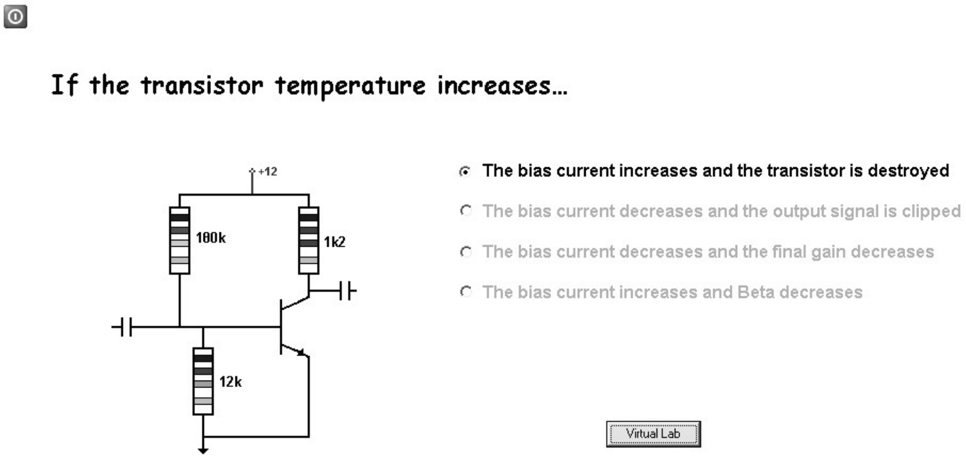
As shown in Fig. 4, when the student leaves the virtual lab, the system displays the question 'Was your answer correct?' to which it is possible to answer 'Yes', 'No' or 'Don't know'.

6.1 *Students academic results*

The marks from the four academic years 2005–06 to 2008–09 were used, taking the following variables into consideration:

1. Carrying out actual lab experiments and skills using lab instruments.
2. Producing actual lab work reports.
3. Actual lab work marks.
4. Score in the controlled assessment on the subject of Transistors.

The sample for this study was made up of four groups of Analogue Electronics students for the



If the transistor temperature increases...

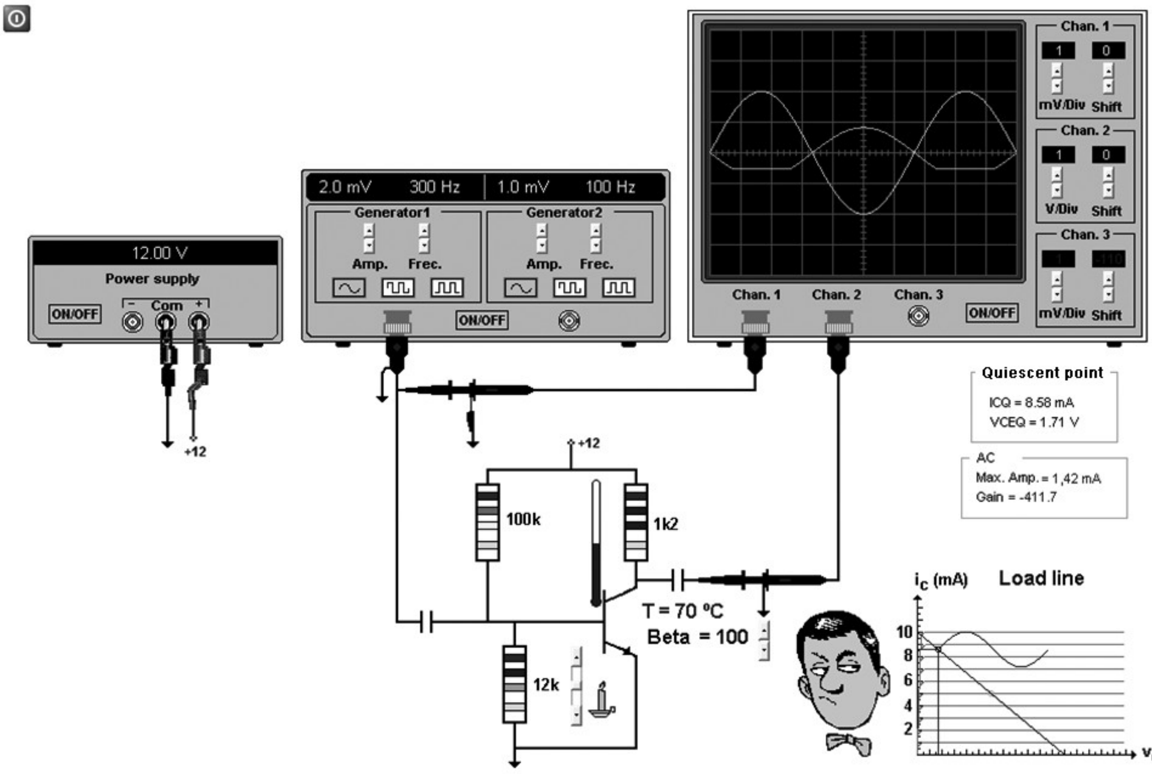
● The bias current increases and the transistor is destroyed

○ The bias current decreases and the output signal is clipped

○ The bias current decreases and the final gain decreases

○ The bias current increases and Beta decreases

Fig. 5. An item from the questionnaire of the transistor self-assessment tool.



Quiescent point
ICQ = 8.58 mA
VCEQ = 1.71 V

AC
Max. Amp. = 1,42 mA
Gain = -411.7

Fig. 6. Link to the virtual lab to experiment with the answer given to the question from the questionnaire.

academic years 2005–06 to 2008–09. The groups consisted of all the students who signed up for the course each year, taking the control groups to be the 2005–06 (38 students) and 2006–07 (40 students) and the experimental groups to be the 2007–08 (33 students) and 2008–09 (35 students). Templates were used to assess the 'Carrying out actual lab experiments and skills with lab instruments' and 'Producing actual lab work reports', and an exam was given involving theory questions and problems to obtain the 'Score in the exam on the topic of transistors'.

The teaching activities that were carried out with the four groups, the two control groups (2005–06 and 2006–07) and the two experimental groups (2007–08 and 2008–09), were the same except for the activity using ISLE. This activity consisted of the teacher using ISLE in the classes and the students then using it independently. The teacher used the ISLE virtual lab to support her theoretical explanations and to test the experiments that students had to perform later in their actual lab work. Students used the hypermedia book, the virtual lab and the ISLE multimedia test tool on their computers running Moodle, and conducting autonomous learning.

As shown in Figs 7–10, students from the experimental groups (using ISLE) got better results than those in the control groups, who did not use this system.

Having seen that there were differences between the means, a statistical comparison was run using the SPSS software package to find out exactly which means differed. To compare the averages, a variance analysis (ANOVA for one factor) was carried out using Tukey contrast [43], which is one of the best accepted methods, with a 95% level of confidence, to check whether there were significant differences between the averages obtained.

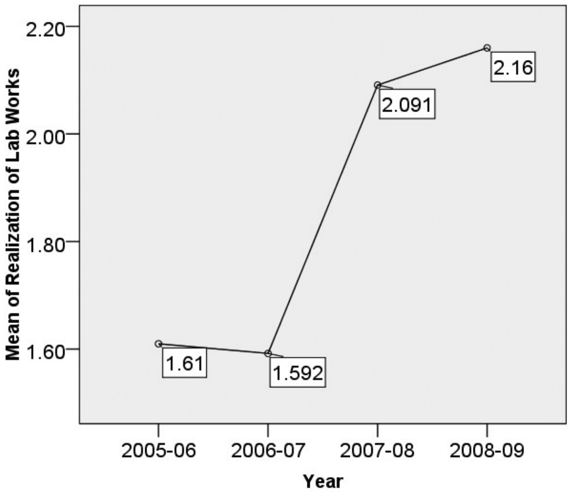


Fig. 7. Average out of the three scores for 'Carrying out real lab experiments and skills with lab instruments'.

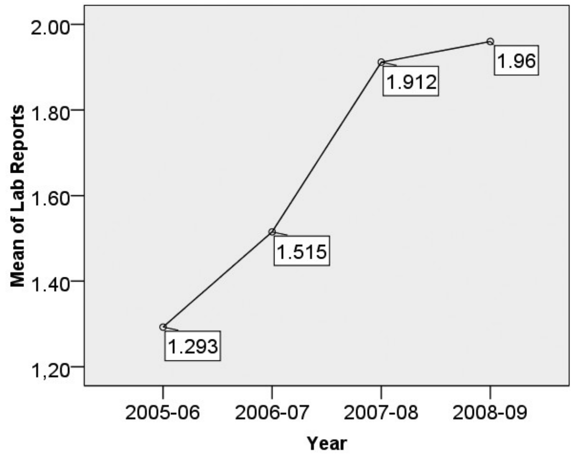


Fig. 8. Average for ‘Producing real lab work reports’.

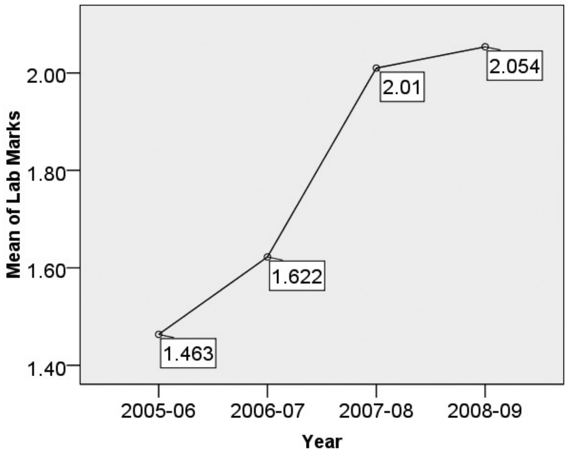


Fig. 10. Average for ‘Lab work marks’.

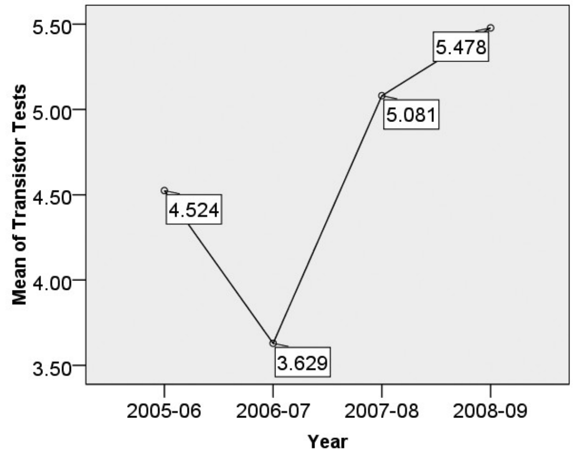


Fig. 9. Average for ‘Score in the exam on the subject of transistors’.

As an example, Table 1 shows a comparison of averages for the variable ‘Carrying out actual lab work and skills with lab instruments’. The difference between the averages has a confidence interval of –0.8235 and –0.1388 in 2005–06 and 2007–08, and –0.9217 and –0.1788 in 2005–06 and 2008–09. As these intervals do not contain 0, this means that the difference between the averages is significant with a confidence level of 95%. The asterisks indicate where the difference in averages is significant. It can therefore be seen that there is a difference of averages in this variable when using ISLE in the experimental years.

Similarly, it can be seen that there are differences in the variables for ‘Producing actual lab work reports’ and ‘Actual lab work marks’.

6.2 Results of the controlled assessment on transistors

The controlled assessment on transistors was implemented in the computer classroom in 2009–10 after completion of the theory teaching activities and before starting actual lab experiments on the same topic. The number of students was 34, the number of questions 11 and the number of different answers 6, as shown in Table 2. The results from using the

Table 1. Completing practicals and skills with instruments (Realisation of Lab Works). Multiple Comparisons. Tukey HSD

					95% Confidence interval	
(I) Year	**(J) Year**	**Mean difference (I–J)**	**Std. error**	**Sig.**	**Lower bound**	**Upper bound**
2005–06	2006–07	0.01792	0.11921	0.999	–0.2919	0.3278
	2007–08	–0.48115*	0.13172	0.002	–0.8235	–0.1388
	2008–09	–0.55024*	0.14292	0.001	–0.9217	–0.1788
2006–07	2005–06	–0.01792	0.11921	0.999	–0.3278	0.2919
	2007–08	–0.49907*	0.12683	0.001	–0.8287	–0.1694
	2008–09	–0.56816*	0.13843	0.000	–0.9280	–0.2083
2007–08	2005–06	0.48115*	0.13172	0.002	0.1388	0.8235
	2006–07	0.49907*	0.12683	0.001	0.1694	0.8287
	2008–09	–0.06909	0.14934	0.967	–0.4573	0.3191
2008–09	2005–06	0.55024*	0.14292	0.001	0.1788	0.9217
	2006–07	0.56816*	0.13843	0.000	0.2083	0.9280
	2007–08	0.06909	0.14934	0.967	–0.3191	0.4573

*The mean difference is significant at the 0.05 level.

Table 2. Numerical results from the controlled assessment on transistors

Number of students evaluated:	34	
Number of questions	11	
No. of answers 0 (Correct answer and then YES)	167	45.88%
No. of answers 1 (Correct answer and then NO)	34	9.34%
No. of answers 2 (Correct answer and then DON'T KNOW)	4	1.10%
No. of answers 3 (Incorrect answer and then NO)	27	7.42%
No. of answers 4 (Incorrect answer and then YES)	125	34.34%
No. of answers 5 (Incorrect answer and then DON'T KNOW)	7	1.92%

controlled assessment module with the students were obtained in a direct form. Once the assessment was completed in the computer classroom, data were collected by the teacher who knew exactly the number of students giving each type of answer. By processing these data, measurements were obtained to find out whether the system was valid or needed some improvement. The numerical results obtained are shown in Table 2.

45.88% of students answered the questionnaire correctly and, after using the virtual lab, they made sure that they had really got it right. We can conclude from this that they used the system as an assessment tool and that the hypermedia book and the self-assessment tool contributed to consolidate their knowledge.

34.34% of students did not answer the questionnaire correctly, but they used the virtual lab to realise they had made a mistake and this helped in their self-learning.

It seems that 9.34% of students have not learnt using the virtual lab and also 7.42% became confused because they gave another incorrect answer. 3.5% of the total students seemed not to follow the subject either in the classroom or using ISLE autonomously.

Therefore, we can say that the ISLE system helped to improve the teaching–learning process of Electronics.

6.3 Analysis of satisfaction surveys

Satisfaction surveys have been carried out at the end of each academic year when ISLE has been used and also after implementing each of the controlled assessment modules. Figure 11 shows the results of the survey taken after the controlled assessment on the transistor topic. The survey used the Moodle 'feedback' tool, always with the same questionnaire. Students were asked how much they agreed (on a scale from 1 to 5) with the following concepts.

1. Browsing in the system is intuitive and no help is required.
2. The design and the figures are clear and easy to read.
3. It makes me think and come up with new ideas and questions.
4. The virtual lab instruments are easy and intuitive to handle.
5. The questions have the right level of difficulty.
6. The virtual lab helps me to answer the questionnaires.
7. I had to consult the theoretical part of the subject to answer the questionnaires.
8. The virtual lab confuses me.
9. I normally use the study material in electronic format.

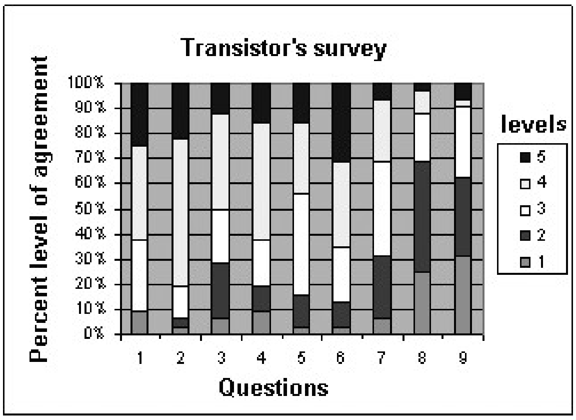


Fig. 11. General assessment percentage.

For the majority of students, browsing is simple and intuitive, the design and the figures are clear and user friendly, and the students believe that it makes them think and come up with new questions. As far as the virtual lab is concerned, most of them consider that they did not need it to answer the questionnaires, it did not confuse them and it was easy to handle the instruments. The majority of the students, in general, continue using the paper format to study as for the statement 'I use the study material in electronic format' they selected values 1 or 2.

7. Conclusions

A teaching–learning system is presented that has been tested with Analogue Electronics students at the San Sebastian Polytechnic University School of the Basque Country, in Spain.

It was verified that using ISLE in the years 2007–08 to 2009–10 helped students to improve their scores and also they were pleased with the methodology. The system has a great pedagogic value, implementing a constructivist methodology and making students aware of their own learning as they have to self-assess whilst they learn. Students therefore are no longer passive recipients of information and become active participants, relating the information available in the system to their experiences and prior knowledge.

The ISLE assessment is continuously performed during the teaching and learning process. Its fundamental aim is not just to regulate it interactively, but also to help students to control their own mental processes and strategies for thinking and learning. In this way the system achieves an authentic assessment, focusing on actual learning situations and significant, relevant problems helping the student to develop valuable knowledge, skills and attitudes.

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