Requirements for the Integral Design of Experiments through Real Laboratory and Simulations in Engineering Education

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ABSTRACT: *Laboratory experiences are closely related to student-centred learning strategies. This practical teaching can be enhanced with the simulation of the real equipment previously used by the students at the laboratory. The usefulness of simulation rely on its element of interaction, and this is broadly characterised as student engagement, which is taken to mean interaction with the simulation with the aim of acquiring or improving understanding. This engaged learning arises from the meaningful nature of the task and is authentic in the sense that it mirrors 'real-life' situations. Three facets of authenticity are the credibility of the simulation, its complexity and whether or not the student has internalised the task. This last feature depends very much on the student's prior experience of the practical situation being simulated.*

A study and revision of the characteristics of simulations that support learning is presented: the attributes, qualities and circumstances of their use that lead to an improvement in a student's understanding. As a result, we can conceive of a basic set of design rules for constructing and using simulations that allows its use together with real laboratory devices to design and conduct experiments in engineering laboratories. The design of simulations in a visual environment has the great advantage of reducing the time necessary to assimilate the content and control the simulation. The previous work at the laboratory allows the comprehension of the phenomena, and the time to master the simulation is small. In addition, the credibility of the simulation is assured due to its fidelity to the real equipment. This integral point of view allows the student to explore the subject more fully and can be very effective in teaching difficult and complex phenomena. Some examples of integral, real + virtual, design of experiments about thermodynamic properties of fluids and thermodynamic cycles are presented.

1 INTRODUCTION

Practical knowledge is a distinctive characteristic of engineers. It involves scientific and technical skills as well as non-technical skills. Amongst the latter we can mention teamwork, creative thinking, communication or critical-self awareness as examples. The industry (BUONOPANE, 1997) demands and expects from engineers a wide range of these generic skills in addition to a high degree of technical competence. Also, many engineering institutions and associations (ASEE, 1994; GRINTER, 1995; ABET, 1997; CAE, 1993; BATES et al., 1992) include this appreciation in their reports. The learning and development of these skills is only possible if, as much as the scientific knowledge, their achievement is a self-building process of the student. Laboratory experiences are closely related to these student-centred strategies and allow a deep approach to learning. Unfortunately, there are several constraints on the provision of practical work at the Faculties of Engineering. These include the costs of equipment and consumables, staff time for developing and supervising students and high student number, which leads to low staff/student ratio and pressure on laboratory space. In some cases it is found that pressures on staff time and laboratory space meant that the students do not conduct practical work at the best time in relation to the presentation of the concepts in the course.

Moreover, probably a great number of engineering professors have asked themselves, at any time, what kind of information and activities could enhance student learning in one of my laboratory classes? Emphasis on handling of apparatus and learning about some experimental techniques has been a traditional approach to laboratory experiences. In recent years, there is a gradual change from teacher-centred to student-centred methods of instruction (FELDER & BRENT, 2003; MONTERO et al., 2004). Besides, the use of computers in undergraduate engineering education has brought a revolution. Computer-based tutorials, generic software tools, simulations, animations, etc., are materials that have the potential to provide an alternative to traditional forms of delivery, such as lectures or laboratory experiences. The computer-based learning tools and the application of the Information and Communication Technologies (ICT) have been frequently used to broaden the teaching strategies. However, some empirical studies (BAHER, 1998; GRINESKI, 1999; BAILLIE & PERCOCO, 2000) suggest that computer-based learning tools can have a negligible or even negative effect on learning if used inappropriately. That means that the introduction of the ICT must be accompanied by improvements in the understanding of learning and teaching.

In relation with laboratory experiments, the practical learning can be enhanced with the use of simulations, a sub-class of computer-based learning tools. From a programming point of view, simulation sits broadly between animations –over which the user has no control save pressing a start and stop button- and virtual reality applications –in which the user is immersed in the environment and which are exemplified by flight simulators. This study presents a revision of the characteristics of simulations that support learning. As a result, we can conceive a set of design rules for constructing and using simulations intended to be used together with real laboratory benches. This integral point of view allows the students to design and conduct experiments to explore the subject more fully and can be very effective in teaching difficult and complex phenomena. Some examples of integral, real plus virtual, design of experiments about thermodynamic properties of fluids and heat engines are presented.

2 ENHANCEMENT OF EXPERIMENTAL LEARNING WITH THE AID OF SIMULATIONS

The laboratory experiences are frequently used as a way to illustrate or check experimental facts and scientific laws presented earlier by the teacher in the classroom. This type of work is usually 'guided' by means of very clear instruction sheets. In other cases, the practical work is as a mean by which to acquire skills in the handling of apparatus or for the learning of specific experimental techniques. Above all in the first stages of learning: the engineering students must learn to measure and to measure well. But the practical work in the Faculties of Engineering can go a step further. If we are to be able to respond to the social requirements mentioned above, then the work students do in the laboratory must be analogous to the behaviour of a real engineer in the exercise of his profession. Such that they can fix their objectives, test their conjectures, work in a team, choose from among various paths, design and follow experimental procedures and analyse and report results, always within situations of a difficulty appropriate to their potential for development.

In some cases, simulations can be seen as an extension to laboratory work in supporting lecture material. Simulations can be defined as computationally correct representations of a situation, which offer the user control over the outcome of the program. The question that arises is in which sense a simulation is useful for learning. The answer will be obtained if some criteria that reflect the values associated with our objectives and with good teaching practices can be formulated. Some relevant Educational Digital Libraries (NEEDS, MERLOT) have already criteria for the evaluation of engineering courseware, and also the examination of some case studies could be of interest (BAHER, 1998; DAVIES, 2002; WOLF & POLI, 2003). For good teaching practices, the work of CHICKERING & GAMSOM, 1987, is a good reference.

Starting from these general references, a set of basic design rules can be conceived. These rules should contain the attributes, qualities and circumstances of use of simulations that lead to an improvement in student's understanding. Following the structure suggested in NEEDS, the criteria are divided into three main categories: instructional design, software design and engineering content. Each category is described by a set of components.

The instructional design deals with the question of if the simulation enhance learning. Will students learn from courseware? Four essential components must be revised:

- Learning objectives are clearly stated and are appropriate. These objectives could be stated in the software or in an instructor's guide. The learners are aware of learning objectives as they are using the simulation. A clear method of measuring achievement of learning objectives is provided.

- Simulation interactivity. That means that the learner is actively involved in the learning process. The choices that students make are meaningful and not just not for the sake of making choices. The students can decide in what order to learn and how deeply they want to concentrate on specific topics. The task presented is meaningful and is authentic in the sense that it mirrors ‘real-life’ situations.
- The content is well chosen and structured. The scope of the simulation content is appropriate for the intended learning objectives and intended audience. The simulation is authentic but emphasis on replication does not lead to an inability to reach the learning goals. The simulation is not ambiguous or is not likely to be misinterpreted by the students.
- Instructions or an instructor’s guide clearly explains how the simulation should be used or the operation is self-evident. Help functions and guides are provided. The software provides different use levels (beginner, intermediate, expert). Sufficient time is allowed for students to master the simulation for arriving at the point at which learning really starts.

The simulation must be well designed and usable. To a large extent, the learner is forced into a particular type of behaviour by the simulation that he is manipulating. In addition, it seems reasonable to assume that if the model held by the programmer is not in accord with the student’s model, then the dislocation between the two will manifest as displeasure with the simulation. The software design category involves three components:

- The software promotes the engagement. The speed of the software is satisfactory. The software is visually appealing and attractive in the design of its screens. The software is stimulating and challenging.
- The simulation possesses a friendly and workable user interface. The navigational instructions are clear and the learner will not get confused about how to proceed. Icons and graphical symbols are clear and unambiguous. Text on screens is appropriately scaled.
- The software is reliable and free from technical problems. There are no interface problems, all buttons function, screen graphics are displayed appropriately and text on screens can not be erased. Software crashes occur very rarely, if at all.

The accuracy of the engineering content is an intrinsic characteristic of simulations. The scientific or technical content must be error free in order to avoid misconceptions.

This engaged learning with simulations is also characterised by learning goals that are intrinsically interesting and by students with intrinsic motivation who actively participate in their learning. These students are able to monitor their progress and recognise when they need help. The property of authenticity makes the students to feel a sense of ownership of the task. Three facets of authenticity are the credibility of the simulation, its complexity and whether or not the student has internalised the task. This last feature depends very much on the student’s prior experience of the practical situation being simulated. Over-emphasis on replication of a scenario, which implies the assumption that high fidelity is better, can lead to an inability to objectively define strategic departures from reality, which might improve learning. As a consequence, although the task must be authentic, the simulation should not be a replication of the real life situation at the expense of the learning goal.

Simulation is a useful and flexible tool. In some cases, the microcomputer simulation replaces not available laboratory equipment, which leads to data that the student can not verify in a ‘real’ experiment. When used in this way, some teachers warn against the fact that the microcomputer does not develop in the students the ‘feel’ for good technical judgements. However, and accordingly to the previous paragraph, the practical teaching can be enhanced with the simulation of the real equipment previously used by the student at the laboratory. In this case, the microcomputer simulation is close to reality and allows the self-learning of the student when the laboratory is not available.

3 CASE STUDY

In this study, two simulations portraying different aspects of two real benches were programmed using the Visual Basic programming environment, version 6.0. The first of them is an air Stirling engine and the second a bench for the determination of the pressure-volume-temperature (PVT) behaviour of pure substances. These simulations and the real equipment are used in the subject of Engineering Thermodynamics, which is taught over a period of 30 weeks, for four hours of timetable contact a week

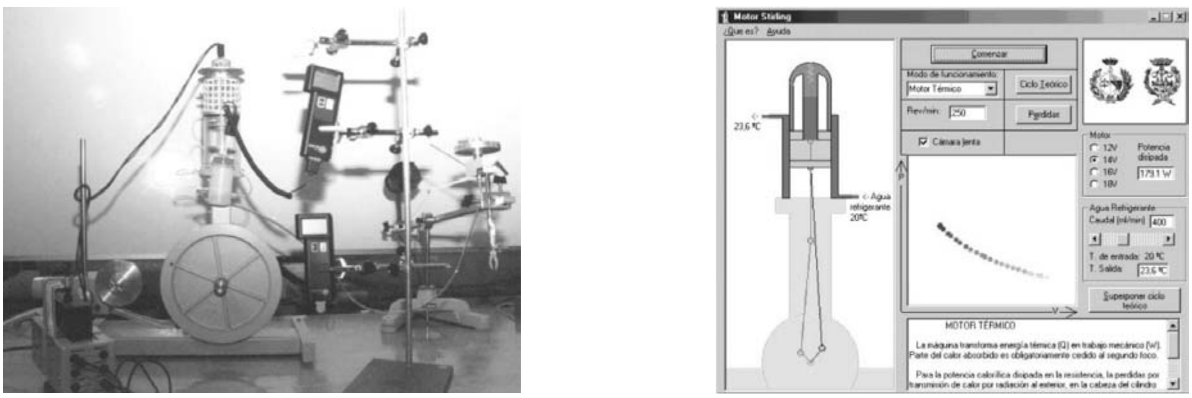
(2 hours theory, 2 hours practical work). This subject is included in the second year of the three-year undergraduate course leading to a degree in Mechanical Engineering at the University of Burgos.

At the laboratory of thermodynamics we have a modern air Stirling unit from Leybold Didactic GmbH (LEYBOLD, 1983). This laboratory equipment works as heat engine or as heat pump/refrigerating machine. In this case, the learning goals are the practical knowledge of the First and the Second Laws of Thermodynamics. At the end of the session, students should be able to:

- Apply the energy conservation balance to cyclic processes (First Law of Thermodynamics).
- Recognise the importance of 'the aim of producing maximum work' for the heat engine or 'the aim of consuming minimum work' for the heat pump/refrigerating machine, through the concept of efficiency (Second Law of Thermodynamics).

First, the students make, under the guidelines of the teacher, a laboratory session of about two hours. When the machine works as a heat engine, the high temperature of the air in the cylinder is provided by an electrical resistance of a maximum power output of 300 W situated in the upper part of the cylinder. A small flow of water supply refrigerates the heat given off by the engine at the lower part of the cylinder. Several experiences at different values of the electrical power and flow rates of refrigerating water are conducted to show the engine performance. When the Stirling unit works as a heat pump or refrigerating machine, a small amount of water in the upper test-tube and the same water supply described above are the heat reservoirs of the engine. Which of them acts as the hot or the cold reservoir depends on the direction of rotation of the disc flywheel, which is driven by a DC electrical motor. This motor also permits to vary the rotation speed of the flywheel. The students can appreciate the qualitative and quantitative effects of direction and speed of rotation of the electrical motor over the temperatures of the hot and cold water. In all cases an optical device allows to see the pressure-volume diagram of the air cycle. The glass construction of the cylinder makes the machine very suitable for instructional purposes but, on the other hand, the glass components will withstand less mechanical and thermal stresses than purely metal parts. The machine therefore requires careful operation and maintenance. For this reason, the machine should not be left unattended whilst in operation. The teacher must be present during all the experiences realised by the students, so the number of experiments that can be developed is small due to limited staff time.

In order to overcome this limitation, a simulation of the machine has been designed. The objective of the simulation must be congruent with the objective of the learner, and must support the learner's objective. In this sense, the simulation must allow the student to acquire a deep knowledge of the significance of the energy conservation related to the efficiency of the engine. Several values of the control parameters of the engine (e.g. the speed of rotation of the shaft in the heat pump or the electrical power of heating in the heat engine) can be employed for this purpose. Insights into the physics of cyclic processes can only be gained if the observations of the energy conversions can be quantified. These measurements must be made with care and are time consuming. The real air Stirling engine and the simulation interface are presented in Figure 1.



(a) (b)

Figure 1 – The Stirling engine: (a) the real device; (b) the simulation interface

As a result, initial experiments with the Stirling unit are carried out at the laboratory. Even taking a few measurements, some understanding of the processes taking place inside heat engines, refrigerators and heat pumps can be obtained. After that, the student is asked to develop a deep study of the machine with the aid of the simulator. The concrete objectives of this second part of the practical work are the following:

- To study the evolution of the heat pump and the refrigerator efficiency as function of the rotation speed of the DC electrical motor.
- To study the evolution of the heat engine efficiency as function of the power of the electrical heater.

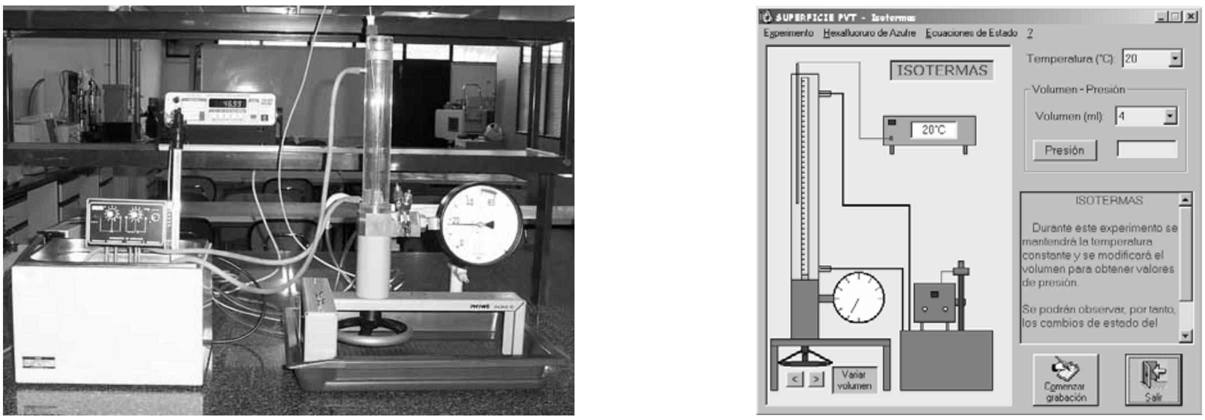
The students have to operate with the simulator and obtain its own results. A final report for assessment has to be written up with the tasks developed with both the real and the virtual experiment.

The PVT bench from Phywe Systeme GbmH (PHYWE, 1996) allows the experimental determination of the pressure-volume-temperature behaviour of a pure substance. In particular, the experimental determination of critical point data and the measurement of the vapour pressure curves. In our case, the substance is sulphur hexafluouride SF_6. Its critical point is at 45,4ºC and 37,5 bar, which means it is a very suitable substance for the experimental study of the liquid-gas phase transition. There are three main components of the device are. First, a transparent compression capillary, melted at one end, calibrated by volume (0-4 ml scale, pitch 0,05 ml). Second, a pressure generating system with pressure gauge (0-50 10^5Pa scale, pitch 0,5 10^5Pa). And third, a transparent container that surround the measurement capillary and that makes it possible to keep the capillary at a constant temperature (0-50ºC), thanks to a water circulation system thermostat. Mercury is pressed from the pressed chamber into the capillary. By this means, a quantity of gas is enclosed in the capillary and compressed by hydraulic pressure transmission. The thermodynamic parameters of pressure, temperature and volume can be specified over the ranges specified.

The learning goal is the practical knowledge of the pressure-volume-temperature behaviour of pure substances, in particular, gases and liquids. At the end of the session, students should be able to:

- Understand the behaviour of the thermodynamic properties of a pure substance during the vapour-liquid transition.
- Use properly the diagrams and tables of thermodynamics properties to obtain accurate information for thermodynamic calculations.

During a laboratory session of two hours, the students carry out some experiences with the PVT device. Initially, the teacher devotes a few minutes to give instructions for measurement and safety operation of the equipment. Afterwards, the students have to plan the experiments they should achieve: how many data and in which order to collect them to obtain the pressure-volume diagram and the vapour pressure curve. The temperature is the property that spends more time to change from one value to another, because the water bath has to even out the temperature with the enclosed quantity of gas. Due to this reason, most of students choose to carry out isothermal processes from ambient to critical temperature. Anyway, the number of data the students can collect in two hours is limited to three or four isothermal processes.



(a) (b)

Figure 2 – The PVT device: (a) the real device; (b) the simulation interface

The PVT simulator allows the students to carry out a more complete set of experiments. They can simulate constant temperature as well as constant pressure or constant volume processes. They can obtain a great number of data with a small time cost. The real PVT device and the simulation interface are presented in Figure 2. The concrete objectives of this second part of the practical work are the following:

- To obtain the pressure-volume thermodynamic diagram of the sulphur hexafluouride, from the ambient conditions to critical point at least.
- To obtain the vapour pressure curve for the same substance.

As with the previous Stirling air engine, the students have to operate with the simulator and obtain its own results. A final report for assessment has to be written up with the tasks developed with both the real and the virtual experiment.

There are some common characteristics to both simulators that address the relevant attributes mentioned above. In order to assure the scientific and technical accuracy of the simulators, a set of experiments were carried out with the real equipment. Involving a task of about 200 hours each, the faculty staff achieved a complete series of experiments that led to a set of error free data about the behaviour of the devices. These data allowed the mathematical characterisation of the processes taking place in the equipment, such as the fitting of data to equations of state in the PVT simulator, for example.

The programming language used to implement the simulations was Visual Basic 6.0. It runs under Windows environment and is based in the event programming. The files size obtained are less than 1 Mbyte and are available in the Web site of the University of Burgos www2.ubu.es/ingelec/maqmot/biblioteca. They have been tested, all the function buttons are operative and free of technical errors. The interfaces have a graphical simulation of the real equipment. For example, in the air Stirling engine, the movement of the disc flywheel and the cylinder, in a section view of the machine. There is a meaningful colour code in this window. When the air in the chamber is cold, it appears in blue. Otherwise, the red colour means that the air in the chamber is hot. The colours, size of the text and the icons and graphical symbols of the interfaces are appropriate.

The learning objectives have been fixed at the beginning of the laboratory session and are written in the instructor's guide. Instructions for the use of each simulator are given in a devoted work session. In addition, a set of instruction pages is posted at the Web site, where the simulators can be downloaded.

Help functions and guides are provided in the screen and also text windows with technical explanations about what is happening during the use of the simulation. Some windows allow student's choices and the simulators response is immediate and meaningful. The microcomputer simulation is close to reality.

4 RESULTS AND DISCUSSION

Thirty students were surveyed in the first semester of 2004. Student attitudes and perceptions to this sort of practical work were gauged in three ways. First of all, students were surveyed at the end of the teaching period through a questionnaire. Second, observations of the behaviour of students were made during the teaching sessions. And third, the evaluation of the scientific designs and reports presented by the students.

An anonymous questionnaire of 20 items was designed to discover student's perception of engagement with the simulation. The attitude information was gathered by the presentation of statements to which students were invited to respond on five-point scales ranging from 'strongly agree' to 'strongly disagree'. Statistical significance of results were analysed by descriptive parameters as modal response (percentage and absolute value), mean value and standard deviation. Table 1 presents the set of statements and statistical results. The questionnaire was conceived in order to elicit information about several dimensions of student's engagement with the simulators such as navigational interactivity, study skills, generic skills and perception of effective learning.

The students have a clear perception that simulations are useful to supplement laboratory experiences rather than to replace them. Statement in question 11 receive the higher score of the questionnaire, mean value 4.12 and standard deviation 0.833, the minimum of the survey. The modal response of agreement (values 4+5) has been the 88% of the total for this question. This evaluation is in agreement with the low score of question 12, which states that simulations can adequately replace traditional laboratory experiences. Most students (30+40=70%) disagree with this opinion.

Table 1. Student's response (% (n)), mean values and standard deviation to 20 mapped statements presented an the questionnaires relating to their use of Stirling and PVT simulators

Statement	5 Strongly agree	4 Agree	**3** Neutral	2 Disagree	1 Strongly disagree	Mean Value	Standard deviation
1. Learning from a simulator is boring	3 (1)	10 (3)	37 (11)	47 (14)	3 (1)	2.63	0.907
2. I prefer to learn from a book than a simulator	3 (1)	0 (0)	20 (6)	54 (16)	23 (7)	2.06	0.878
3. The simulators allow me to work at my own pace	7 (2)	42 (12)	45 (13)	3 (1)	3 (1)	3.42	0.848
4. The simulators offer more flexibility of use than laboratory experiences	7 (2)	54 (16)	13 (4)	23 (7)	3(1)	3.35	1.018
5. The simulators allow me to choose where and when study	7 (2)	37 (11)	37 (11)	20 (6)	0 (0)	3.34	0.902
6. I learn more from a laboratory experience than a simulator	23 (7)	30 (9)	23 (7)	17 (5)	7 (2)	3.47	1.191
7. A laboratory experience is a better way to learn a topic than a simulator	17 (5)	42 (12)	24 (12)	17 5)	0 (0)	3.48	1.029
8. I am worried that I will not be able to use to use the simulator (using computers is a major problem to me)	0 (0)	17 (5)	30 (9)	33 (10)	20 (6)	2.41	1.012
9. When using simulators I would prefer to work with a friend so we can discuss the problems that arise	27 (8)	57 (17)	10 (3)	3 (1)	3 (1)	4.03	0.897
10. When using simulators I would prefer to work on my own	3 (1)	3 (1)	24(7)	56 (16)	14 (8)	2.26	0.893
11. I would like to use simulators to supplement rather than replace laboratory experiences	33 (10)	50 (15)	10 (·3)	7 (2)	0 (0)	4.12	0.833
12. Simulators can adequately replace traditional laboratory experiences	7 (2)	7 (2)	17 (5)	30 (9)	40 (12)	2.13	1.238
13. I would prefer to work with simulators rather than attend traditional practical sessions	7 (2)	13 (4)	17 (5)	43 (13)	20 (6)	2.50	1.164
14. Simulators suit my needs better than traditional laboratory experiences	3 (1)	23 (7)	30 (9)	33 (10)	10 (3)	2.78	1.008
15. Simulators can readily teach experimental facts and substitute laboratory experiences on the same topic	3 (1)	27 (8)	10 (3)	57 (17)	3 (1)	2.66	1.004
16. As method of teaching, simulators and traditional laboratory experiences can be equally effective	3 (1)	23 (7)	30 (9)	43 (13)	0 (0)	2.84	0.884
17. A simulator addresses similar learning needs to a traditional laboratory experience	3 (1)	13 (4)	27 (8)	54 (16)	3 (1)	2.75	1.047
18. Laboratory experiences and simulators can provide me with similar levels of information and experience	7 (2)	35 (10)	17 (5)	38 (11)	3 (1)	3.10	1.076
19. With the simulators I have missed being able to ask the lecturer when I didn't understand something	17 (5)	43 (13)	23 (7)	10 (3)	7 (2)	3.47	1.107
20. Laboratory experiences are better than simulators at presenting information	7 (2)	27 (8)	40 (12)	27 (8)	0 (0)	3.22	0.941

The previous discussion is confirmed by the perception of practical learning. The students show a slight preference of experiential learning (question 6, m.v. 3.47, s.d. 1.191; question 7, m.v. 3.48, s.d.

1.029) and also consider that experimental facts can not be totally substituted by simulations (question 15, m.v. 2.66, s.d. 1.004). This expresses a need of laboratory experiences prior to the use of simulations in order to assure credibility.

Another issue well considered by students is the fact of using the simulation with other students. A majority reported that, when using the simulation, they prefer to work with a friend (question 9, m.v. 4.03, s.d. 0.897) rather than to work in their own (question 10, m.v. 2.26, s.d. 0.893). That means that simulation with a computer promotes co-operative learning instead of being a lonely task.

Concerning learning styles, answer to question 2 shows that 77% of students prefer to learn from a simulation rather than a book (m.v. 2.06, s.d. 0.878). Only one student prefers clearly the book. This preponderance relates with the fact that the new generations of students are more acquainted with the use of computers, because the enormous development of ICT at schools and households. In this sense, the simulations use to be friendless due to its interactivity, which means a quality for engagement.

The perception of that effective learning from simulations can be equally effective than laboratory experiences has the modal responses in disagreement (question 16, 43%; question 17, 54%). In respect of the level of information and experience that can be provided, though question 18 present a centred mean value, 3.10, the dispersion is significant. The modal responses of agreement and disagreement are 35% and 38%, respectively, being 17% neutral. That means that there is a great variety of learning styles and that the supplementary use of simulations address some of them that are not covered by experiential style.

Questions 1, 3, 4, 13 and 14 address issues of study style. Question 1 (m.v. 2.63, s.d. 0.907) that a great number of students (47%) enjoyed using the simulations, though 37% of them were neutral. Questions 3 and 4 shows that the flexibility of use of the simulation is valuable. However, the students are slightly in disagreement with the statement that the simulators match completely its study style (question 13, m.v. 2.50, s.d. 1.164; question 14, m.v. 2.78, s.d. 1.008). Though both simulators are provided with help buttons and explaining text windows, some students have missed the opportunity of asking the lecturer when they didn’t understand (question 19, m.v. 3.47, s.d, 1.107).

Question 8 is related with the difficulties to use the software. Most of students (33+20=53%) find difficulties to use, while an additional 30% is neutral. That means that a major effort in instructional efficiency is required. This aspect could be also related with the allowance to choose where and when study (question 5, m.v. 3.34, s.d. 0.902), During informal interviews with students, one of the main problems found was the fact that the University has an insufficient number of computers for student’s free use. Furthermore, not all the students have a computer at their own home. Though the simulation is available for download at the Web site, the teacher has been compelled to give floppy disk copies to some students. So, the supposed easiness of access was not really true.

During teaching sessions and tutorial activities, some additional information has been collected. The design of the simulation in a visual environment, very well known by students, has been a great advantage to reduce the time necessary to assimilate the content and control of the simulation. The previous work at the laboratory has permitted the comprehension of the phenomena of energy conversion and the time to master the simulation was small.

It is clear that students do not solely interact with the simulation. The whole environment is important for fully engaged learning. The on-line discussion demands some collaboration: the students have to interact, to share their knowledge and to adjust their own way of learning. It is a fact that, from several years ago, the practical work in Engineering Thermodynamics is developed at groups constituted habitually by four students. The group does the laboratory work, the briefings and reports. Also the assessment activity is centred in the group. So, the collaborative discussion of the simulation results is one more, not new, of the activities of these groups of students.

6 CONCLUSIONS

The study was designed to evaluate the practicality and effectiveness of two simulators programs intended to supplement traditional laboratory experiences in Engineering Thermodynamics. These simulators are used in an independent learning situation in which there was no direct tutor support but after a direct experience with the real equipment at the laboratory. The main purpose of this study was to establish whether students could adapt to this method of learning and investigate other issues that might affect this.

Education is frequently conservative in attitude and practice, with students as likely as teachers to be comfortable with traditional approaches. For most of students participating in this study, the experience described here constituted their first real encounter with a significant use of simulation as a learning resource. The results presented show an evidence of the student's satisfaction with the simulations as a viable alternative to laboratory experiences. They appeared satisfied with their own experience of the balance between simulations and conventional laboratory work.

It was not clear from the information collected in this study how student's working time preferences were established. Clearly, increased use of computer based learning tools as learning resources requires adequate provision by the institution and unimpeded access for students. Although increased use of learning opportunities, including computer based learning, will increase pressure on resources, it may free students to be more flexible in their calls upon these resources an in their use of time.

Students participating in this study identified some benefits of the simulators. Students move towards collaborative work and discussion, enhancing the teamwork culture already developed at the laboratory. The engagement with the simulation is acceptable and broad the opportunities of learning by addressing to different learning styles. The effective learning is improved by means of the authenticity of the simulation. The credibility of the simulation is assured due to its fidelity to the real equipment. Experience of working with the simulations influence student opinion in a way favourable to the approach, while they still retain a preference for mixed methods in which the simulations plays a part alongside more conventional approaches.

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