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THE APPLICATION OF DIDACTIC VIRTUAL TOOLS IN THE INSTRUCTION OF INDUSTRIAL RADIOGRAPHY

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ABSTRACT

In this article an interactive virtual platform (IVP) is introduced to be used in the instruction of industrial radiography. The design of this virtual tool is the result of a collaborative process between teachers and students and, therefore, this X-ray IVP includes the characteristics that both groups demand. Students' opinion reflected in several surveys guarantee that this IVP is an educational and motivating virtual resource. Furthermore, the students' opinion about several fundamental characteristics of virtual didactic tools is also included in this article, namely: (i) realism, (ii) interactivity, (iii) ease of use, (iv) real time, (v) motivation and (vi) didactic quality.

Keywords: *virtual didactic tool; industrial radiography; virtual laboratory; welding defects*.

INTRODUCTION

Industrial radiography is a non-destructive testing technique that is used in the evaluation of pieces due to the fact that it facilitates the detection of possible faults or imperfections in their interior[1]. This type of test is based on electromagnetic radiations (X-rays or γ-rays), which are capable of penetrating any material because of the shortness of their wavelength[2]. One of the most common uses of this technique in the industrial sector it is the evaluation of moulded parts and welded connections[3].

In spite of the professional importance of industrial radiography, there are no books at the university teaching level that deal this topic with the relevancy which it deserves. Specifically missing are examples/illustrations indicating the radiographic aspect of the most common typologies of welding defects, as well as providing exercises to reinforce the knowledge in this area, etc. In fact, there are more and more websites –the only advisable bibliography nowadays for engineering students– where the authors explain the implication of industrial radiography in the evaluation of welds in a didactic environment[4,5]. Some teachers are, however, applying innovative educational methodologies to foster an active educational program in industrial radiography[6].

On the other hand, due to the possible problems of radiation that the use of this type of machinery in real life entails, practical classes of this topic usually cannot be taught in a technical school, remaining restricted to theoretical classes. In fact, the practical teaching of industrial radiology in an engineering school presents serious administrative disadvantages due to the regulation and the laws involved in the use of radiological devices. A possible solution would be to resort to a virtual environment that would help to show this practical part to the students, but nowadays there is no commercial didactic tool to solve this problem and neither is there any evidence of teachers who have designed a virtual application with an educational purpose in this area.

Therefore, in order to overcome this lack, a virtual laboratory is described in this article where the student can do an X-ray photograph of a weldment in an interactive way and, in addition, the student can also solve a collection of virtual exercises to assess his/her knowledge about the welding faults found in X-rays of weldments. The basic aim of the virtual resource presented in this article is purely didactic and it will be used for students to (i) assimilate the functioning of an X-ray machine and, (ii) solve a series of virtual exercises that reinforce their knowledge of the detection of the typical welding discontinuities.

VIRTUAL PLATFORM

The virtual didactic tools that allow the student to interact freely with them, favour a process not only of self-learning but also of social interaction with his/her classmates[7]. Thus, these simulations not only assure a better comprehension of the functioning of the machines used in the practices of different subjects of engineering but in addition they guarantee a productive type of learning, i.e., they develop the habit of thinking, of reasoning and relating or of explaining the information[6]. On the other hand, it is necessary to bear in mind that, according to previous studies[8], engineering students prefer using specific programs developed for a specific subject instead of generic commercial applications. Keeping this in mind, the authors of this article have designed an Interactive Virtual Platform (IVP) that simulates the functioning of an X8008 model industrial radiology machine of the company Viscom AG Vision Technology (Figure 1). In this regard, the IVP tool can turn out to be very useful in various technical qualifications applications where the detection of faults by means of industrial radiography, mainly in moulded or welded pieces, is part of the instructional agenda, e.g., Industrial Engineering, Civil Engineering, Building Engineering, Materials Engineering, etc.).

Figure 1. IVP designed by authors..

Quest3D® and 3D Studio Max® environments were used to design this tool. The joint use of both programs helps the virtual designed tool to be three-dimensional (3D), interactive, very realistic, easy to use, pleasant and motivating, with real time movements and, in addition, it allows implementation of a didactic complement to reinforce the knowledge of the topic of study. With the 3D Studio Max® program the three-dimensional surroundings of the laboratory, the furniture and the X-ray machine were modeled, assigning different materials to each and creating the appropriate lighting. All these aspects were achieved looking for the major degree of realism for an application in real time. Later, the models obtained were exported to Quest3D®, which includes a graphical engine in time of execution and a system of visual programming orientated to objects. In this program, both the interactivity of movement through the scene (virtual laboratory) and the interaction with the elements mentioned were incorporated. This program uses the Direct X technology that is easily accessible to any user, since he/she only needs a graphical card with the technology mentioned above. Quest 3D® presents several advantages over other programs that purport to implement visual interactive components[9]:

- Speed of integrating or suppressing elements in the model,
- Simplicity at the moment of defining the flow of work,
- Flexibility to change the geometry and characteristics of the components in the model,
- 3D visual integration with the ability to import and export entities of other sources,
- Accessibility for any educational entity by means of academic licenses,
- The programming is based on the philosophy of WYSIWYG (What You See Is What You Get), i.e., results are seen directly in the program without need to render or to export the application in order to verify if the programming was done correctly.

All these aspects are what favoured the decision of the authors of the present work to use this environment to design the IVP of industrial radiography.

It is convenient to specify that the virtual tool presented in this article has undergone an evolution with time[10], from the first version up to the current one in which the aspects of improvement that the pupils demanded as they used it have been included. This way, the IVP of X-rays presents some really interesting properties from the educational point of view[11]: (i) realism, (ii) interactivity, (iii) ease of use, (iv) real time, (v) motivation and (vi) didactic quality.

Figure 2. Environment of the simulated laboratory.

(a) (b)

Figure 3. Testing materials: (a) real part, (b) 3D scanned parts.

Figure 4. X-ray obtained in the IVP.

The realism of the virtual environments is an aspect that awakes a great interest in students[12], mainly when these are created in three dimensions. In this regard, the X-ray IVP that is analyzed –developed in 3D– bears in mind several aspects:

- The X-ray machine itself (Figure 1),
- The virtual environment of the laboratory itself, including even the exterior environment to this one that shows a virtual simulation of the campus itself (Figure 2),
- The test materials, which were obtained by the use of a 3D scanner applied to a real weldment (Figure 3),
- The virtual X-rays obtained in the IVP, which were digitized from real X-ray photographs (Figure 4).

The environment applied in this IVP is similar to the one employed in videogames known as the "shooter", in which the user visualizes the environment in the first position and, from this perspective, the environment provides *per se* a major degree of realism. In addition, the simulation of the functioning of the virtual machine up to obtaining the X-ray of a piece was assured in the most real way as possible, following the same steps that must be taken in the reality and including aspects that identified the real world, e.g., the sound of the machine running, of the turning on and off of the virtual computer, etc.

On the other hand, the property of interactivity is one of the most valued for an IVP[12-16]. This property assumes that the student perceives the virtual didactic tool as a video game, since both use very similar software. The main aim of this characteristic is to make the study turn out to be much more pleasant and attractive to the student body. The present industrial radiography IVP has been designed in order to allow the users to interact freely with it, manipulating it with the mouse of the computer and certain keys of the keyboard (see controls in Figures 1-4). As a result, the student can freely move through the virtual laboratory of this IVP, being positioned in any point of the three-dimensional space and being able to visualize the environment from any point of view and perspective.

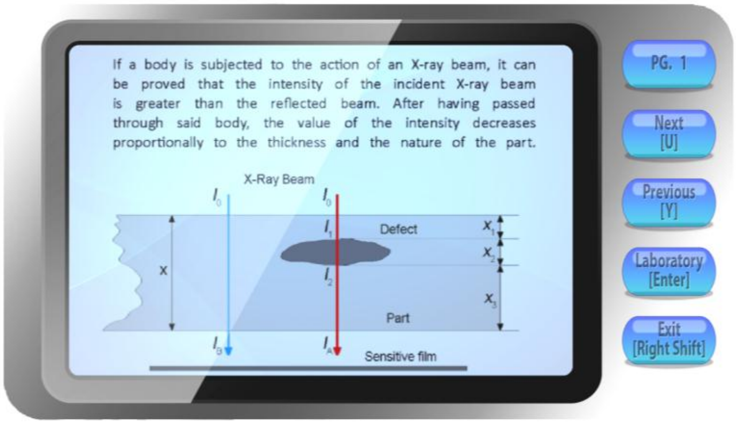
Inside the area of virtual tools, teachers always look and try to make the virtual interface as intuitive as possible[17]. Thus, in order to design a really easy to use IVP it is suitable to do tests with the student body before obtaining the final version. In this regard, considering the indications of the students who previously used versions of this X-ray IVP, the current version includes the following changes in order to make its use be easier and more intuitive to the user:

- Direct placement of the piece to be analyzed in the X-ray machine,
- Presentation on the virtual computer screen of an as close to real as possible X-ray (Figure 4),
- Presentation of a simple, clear and detailed key of movements (see controls in Figures 1-4).

With regard to the importance of interacting in real time, it is necessary to bear in mind that the current community demands a rapid and immediate response in any device. In fact, the most demanded video games are those that provide an immediate response to an action[18] –feedback– and, on the contrary, those that do not do it become obsolete. Keeping this in mind, this IVP of industrial radiography is based on creating an environment similar to those of first-person shooter video games, achieving in this way that the movements take place in real time. First-person shooters and third-person shooters are different types of 3D shooter game[19]. The first one features a first-person point of view with which the player sees the action through the eyes of the player character. In the case of third-person shooters the player can see the character he is controlling. These games developed in a 3D environment tend to be somewhat more realistic than 2D shooter games[20]. The similarity of didactic IVPs with this type of video games (3D shooter) helps to give a sensation of modernity in the virtual tool, which manages to awake the curiosity in the student so he/she continues investigating the use of this educational technology (reinforcing in this way the didactic content of the platform).

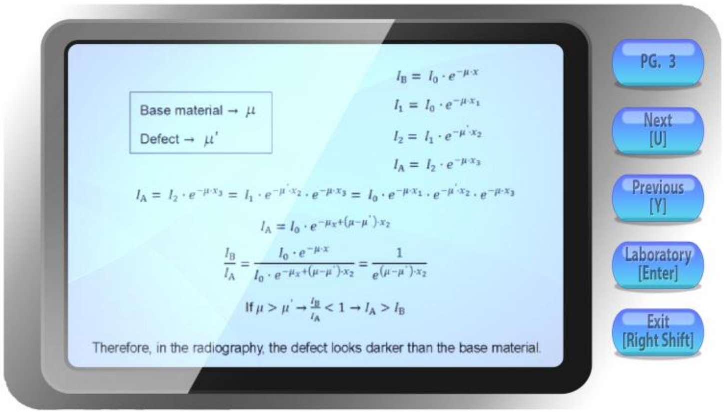
The motivation that the IVP awakes in the students is actually a consequence of the previously analyzed properties, since it depends directly on them. Though it is clear that an educational technology is not a video game, many students compared this IVP with one of them (surely due to the type of environment which it has been designed in and the possibilities of movements and applications it presents). This fact can enhance the motivation of the students and, therefore, attract them towards the study of industrial radiography. Although there are lots of examples of virtual environments designed in 2D, which are applied, in engineering qualifications[21-27], the current trend is focusing towards designing in 3D[7,11-12]. In spite of the importance that virtual three-dimensional laboratories have because they imply a major realism that favours the motivation of the student[12], the authors have still not found any didactic application based on a "3D shooter" environment for industrial radiography teaching. This 3D environments typology, besides motivating the student to bring him/her closer to a virtual world similar to the one of a video game, manages to transmit some didactic knowledge to the student. Therefore, this IVP supposes a new approach of the educational technology applied in the university teaching.

The virtual environments applied in the educational sector can enrich the processes of education learning if they present a good didactic quality. In this regard, the student body that used the first versions of this IVP demanded a collection of virtual exercises to complete and to improve the educational application of the tool[10]. Taking students' comments into consideration, an access to virtual documents with the basic theory of the industrial radiography was included in the IVP (Figure 5). These documents are available at all time in order to enable a better understanding of the study subject. Besides, several test versions of a new educational application were also created and were included in the virtual environment of the IVP. All of them were tested and examined by the students before obtaining the final version here presented. The purpose of this educational complement is to help the student body to recognize the typical welding discontinuities (Figure 6) and, in addition, to turn it out to be easy and intuitive to handle. Consequently, a collection of exercises has been included in the virtual computer of the IVP. They are based on clarifying the typologies of discontinuities that certain real X-rays of weldments present, e.g. excessive penetration, root concavity, incompletely filled groove, external and internal undercut, linear misalignment, cracks, lack of side fusion, inclusions, porosity, etc. From these exercises with virtual X-rays the teacher can ask the student to identify the type/s of defect/s that the welded piece has, to comment the possible errors of execution of the welded piece, etc., i.e., the teacher can raise different questions related to industrial radiography so that the students develop the concepts learned during the previous theoretical classes. This fact implies using a more active methodology than the traditional lecture class. Later the student can gain access to the solution, which is also implemented in this educational virtual complement. Even so, it is convenient to make clear to students that in real life there are already automated processes for the digital analysis of the welding discontinuities and defects, which are even more effective than the human recognition[28-30].



If a body is subjected to the action of an X-ray beam, it can be proved that the intensity of the incident X-ray beam is greater than the reflected beam. After having passed through said body, the value of the intensity decreases proportionally to the thickness and the nature of the part.

(a)



Base material → μ
Defect → μ'

$$I_B = I_0 \cdot e^{-\mu \cdot x}$$
$$I_1 = I_0 \cdot e^{-\mu \cdot x_1}$$
$$I_2 = I_1 \cdot e^{-\mu' \cdot x_2}$$
$$I_A = I_2 \cdot e^{-\mu \cdot x_3}$$
$$I_A = I_2 \cdot e^{-\mu \cdot x_3} = I_1 \cdot e^{-\mu' \cdot x_2} \cdot e^{-\mu \cdot x_3} = I_0 \cdot e^{-\mu \cdot x_1} \cdot e^{-\mu' \cdot x_2} \cdot e^{-\mu \cdot x_3}$$
$$I_A = I_0 \cdot e^{-\mu x + (\mu - \mu') \cdot x_2}$$
$$\frac{I_B}{I_A} = \frac{I_0 \cdot e^{-\mu \cdot x}}{I_0 \cdot e^{-\mu x + (\mu - \mu') \cdot x_2}} = \frac{1}{e^{(\mu - \mu') \cdot x_2}}$$
$$\text{If } \mu > \mu' \rightarrow \frac{I_B}{I_A} < 1 \rightarrow I_A > I_B$$

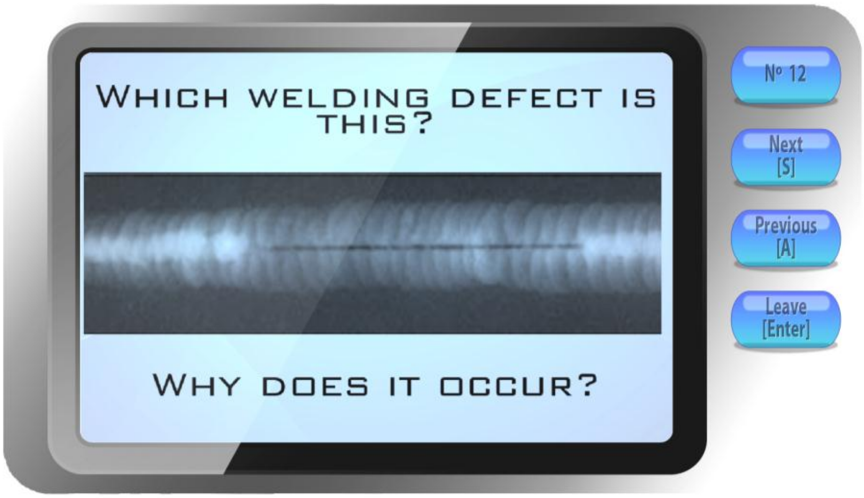
Therefore, in the radiography, the defect looks darker than the base material.

(b)

Figure 5. Some examples of basic theory accessible from the IVP:

(a) Page 1 in the IVP;

(b) Page 3 in the IVP.



WHICH WELDING DEFECT IS THIS?

WHY DOES IT OCCUR?

Figure 6. Educational complement.

STUDENTS' OPINIONS

The valuations of the properties of the present IVP that are shown in both Table 1 and Figure 7 correspond to the arithmetic mean of the answers given by eighty students belonging to different engineering qualifications (civil engineering and industrial engineering). The six properties have been really well valued for this didactic tool, making it possible to affirm that the IVP presents a propitious design to be applied in the classroom. Even so, considering the statistical dispersion measures, the first four properties –(i) realism, (ii) interactivity, (iii) ease of use and (iv) real time– have a low standard deviation that never exceeds the value of 0.5 points, which indicates that the opinion of the students is very similar regarding these four properties of the IVP. In fact, the students' valuation ranges from 9 to 10 in all cases. On the contrary, regarding the last two properties –(v) motivation and (vi) didactic quality– the standard deviation is around 1.0. This indicates that, in spite of such a high average, the opinion of the students differs some more in these cases. Some of them are completely sure of the fact that this IVP motivates the study of the industrial radiography and others, though giving a high valuation, are not so sure. Even so, the range of values fluctuates between 7 and 10 points, i.e. the general valuation of students is really high for both properties of the IVP, not only for the didactic quality but also for the level of motivation of the students in order to continue using the IVP.

There is doubt cast on the effectiveness of using this type of technology in education, but seeing the average value and the range of values obtained in students' surveys (Figure 7) this query remains absolutely rejected. On the other hand, since there is a standard deviation of 1.0 in the valuation of the didactic quality (Table 1), an extension of the educational complement could be necessary. According to the suggestions of the student body, several examples of each one of the typologies of welding fault should be included and placed in a random way in the educational complement of the IVP, reinforcing in this way the process of memorization. Students can enhance their knowledge of industrial radiography even more if the IVP provides more than one example of each welding fault. The authors consider that these measurements should be appropriate to improve the last two properties of the IVP –motivation and didactic quality– and, consequently, to enhance the students' opinion about them.

Table 1. Some examples of survey questions.

QUESTION	ARITHMETIC AVERAGE	STANDARD DEVIATION
Value from 1 to 10 the property "realism" of the IVP.	9.8	0.36
Value from 1 to 10 the property "interactivity" of the IVP.	9.7	0.43
Value from 1 to 10 the property "ease of use" of the IVP.	9.3	0.50
Value from 1 to 10 the property "real time" of the IVP.	9.8	0.39
Value from 1 to 10 the property "motivation" of the IVP.	9.0	1.05
Value from 1 to 10 the "didactic quality" of the IVP.	9.4	0.98

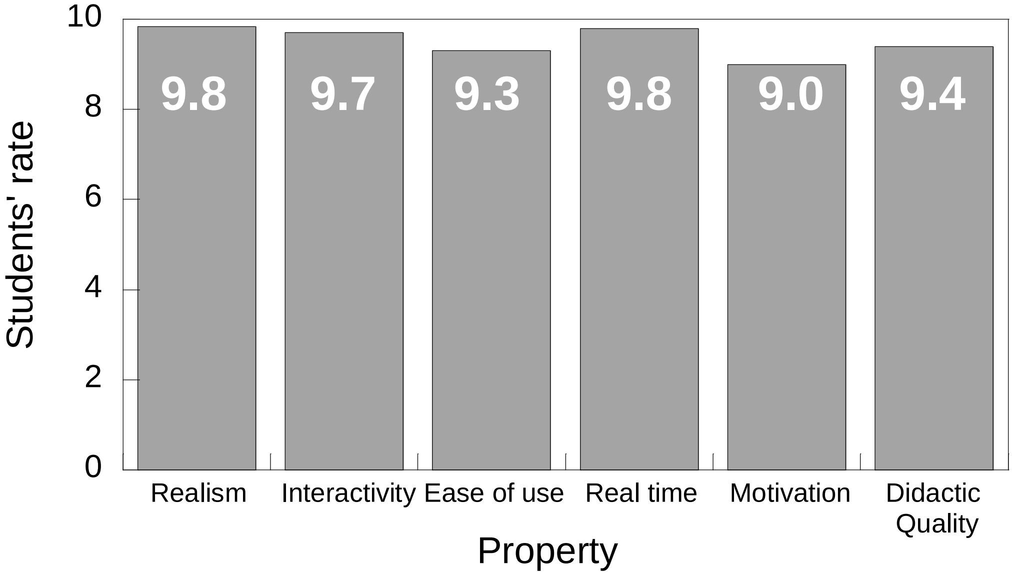


Figure 7. Students' valuation of the IVP.

Another change demanded by the students is that the IVP is left on the network so it could be available at any time. In the face of this demand, the authors are working in this direction to create a web page to hang the IVP of X-rays but its implementation in the network presents several disadvantages due to the application with which it has been created, Quest3D®. In the first place, only one file of great size is created, which is very useful to install from a CD or pen drive but very difficult to manage to use from Internet. Of secondary importance is that if the file is left on the network any user could download and make an undue use of it, without taking in consideration the corresponding copyright. The solution to these two problems is to use another programming environment (different from Quest3D®) that is focused on the web, which optimizes both the transmission of information and the size of the files and, particularly, it allows users to handle it only when they are connected. To this end, there are several options: (i) programming everything in Java, though it is very complicated and nowadays it is not very optimized for 3D graphs; (ii) using other environments as Unity3D®, that manages these graphs very well and, in addition, allows their use from other fixed or mobile systems (Android, Apple, Windows, etc.). Bearing these possibilities in mind, the authors expect to make this tool operative in the web in a future, but for the moment they have hung a short video-demonstration on a YouTube link[31], where readers of this paper may appreciate the didactic potential of this tool.

DISCUSSION AND CONCLUSIONS

According to previous studies[21,32], the use of virtual environments enhances development of professional skills. Even so, the important thing is not actually the use of this type of educational technology, but how these are designed and how the teacher applies them in the classroom to fully exploit their educational potential. In this sense it is very important to design the virtual didactic tool as a collaborative process between teacher and students. Following this principle, the IVP presented in this article has undergone several updates from its first version up to the current design, which also includes an educational complement in order to learn the typologies of discontinuities and defects that weldments present. To reach the current IVP, the opinion of the student body was really essential in order to design and to improve this virtual didactic tool for the teaching of industrial radiography.

This IVP facilitates the educational focus and besides, since it allows a free interaction with it, students enrolled in technical degrees can understand the functioning of industrial X-ray equipment better than in case of traditional lecture classes. In addition, this virtual tool overcomes the disadvantage of not being able to teach a practical class in this subject, due to the problems of radiation and the legal regulation that restricts use of this type of machinery. On the other hand, it is important to clarify that the X-rays obtained by means of this IVP do not correspond with the actual X-rayed virtual piece (this is impossible according to the principles of industrial radiology and would suppose an important scientific revolution). Even so, these virtual X-rays are copied from real X-rays and, at a didactic level, they make it possible for students to identify and understand the different types of welding defects that exist.

Students' opinion reflected by the surveys guarantee that a suitable degree of design of this didactic X-ray IVP has been reached and, in this way, its application in the classroom is really useful. Therefore, as a final conclusion, the authors want to emphasize that the process of designing this type of virtual educational technology is an evolutionary process in which the weaknesses detected and identified by the student body are constantly modified and updated (collaborative process between teachers and students). The authors consider that this example of application of IVP in industrial radiography can be an inspiration to other professors in order to apply didactic virtual tools in his/her subjects.

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REFERENCES

1. M.K. Felisberto, T.M. Centeno, L.V.R. Arruda, and H.S. Lopes, 10th SEM International Congress on Experimental and Applied Mechanics, Costa Mesa (CA), USA, 2004.
2. J. Lang, and A. Middelton, Radiography of cultural material, Ed. Elsevier Butterworth-Heinemann, Great Britain, 2005.
3. N. Nacereddine, and M. Tridi, Proceedings of the 4th International Symposium on Image and Signal Processing and Analysis, Zagreb, Croatia, 2005, pp. 88.
4. *http://www.ndt-ed.org/EducationResources/CommunityCollege/Radiography/TechCalibrations/RadiographInterp.htm*

5. *http://gafoorxspeed.com/industrial-radiography1.html*

6. D. Vergara, and M.P. Rubio, *J. Mater. Ed.* **34**, 175 (2012).

7. A.C. da Silva, and N. Felix, *Educação Gráfica* **15**, 7 (2011).

8. R. Barrio, J. Parrondo, E. Blanco, and J. Fernández, *Revista de Formación e Innovación Educativa Universitaria*, **4**, 55 (2011).

9. R. Pérez, S. Jöns, A. Hernández, and D. Young, *Conciencia Tecnológica*, **41**, 28 (2011).

10. D. Vergara, M.P. Rubio, and F. Prieto, *Revista Iberoamericana de Educación en Tecnología y Tecnología en Educación*, **11**, 76 (2013).

11. D. Vergara, M. Lorenzo, and M.P. Rubio, *Virtual environments in materials science and engineering: the students' opinion*, Chapter in *Recent Developments in Materials Science and Corrosion Engineering Education*, ed. H.L. Lim, IGI Global Publishers, (*in press*).

12. B. Balamuralithara, and P.C. Woods, *Comput. Appl. Eng. Ed.* **17**, 108 (2009).

13. R. Tori, R. Nakamura, F.L.S. Nunes, J.L. Bernardes, M.A.G.V. Ferreira, and E. Ranzini, *SBC J. 3D Interact. Syst.* **2**, 94 (2011).

14. L. Barreto, A. Vilaça, and C. Viana, *IEEE Multidiscip. Eng. Ed. Mag.* **4**, 13 (2011).

15. D. Vergara, M.P. Rubio, and M. Lorenzo, *IEEE Tech. Eng. Ed. (ITEE)* **7**, 44 (2012).

16. D. Vergara, M.P. Rubio, and M. Lorenzo, *Key Eng. Mater.* **572**, 582 (2014).

17. Ö. Karagöz, and N. Özdener, *Bulgarian J. Sci. Ed. Policy* **4**, 216 (2010).

18. M. de Aguilera, and A. Méndiz, *ACM Comp. in Entertainment* **1**, 1 (2003).

19. A. Rollings, and E. Adams, Fundamentals of Game Design, Ed. Pearson Prentice Hall, 2007.

20. R. Rouse, Game design: Theory and practice, Second edition, Ed. Jones & Bartlett Learning, 2010.

21. D. Shin, E.S. Yoon, S.J. Park, and E.S. Lee, *Comp. Chem. Eng.* **24**, 1381 (2000).

22. F.A. Candelas, S.T. Puente, F. Torres, F.G. Ortiz, P. Gil, and J. Pomares, *Int. J. Eng. Ed.* **19**, 363 (2003).

23. P. Bhargava, J. Antonakakis, C. Cunningham, and A.T. Zehnder, *Comput. Appl. Eng. Ed.* **14**, 1 (2006).

24. I.E. Chika, D. Azzi, J. Stocker, and B.P. Haynes, *IEEE Multidisciplinary Eng. Educ. Mag.* **3**, 112 (2008).

25. C. Chan, and W. Fok, *Eng. Ed.* **4**, 70 (2009).

26. L.A. Dobrzański, and R. Honysz, *J. Mater. Ed.* **31**, 131 (2009).

27. L.A. Dobrzański, and R. Honysz, *J. Achievements Mater. Manuf. Eng*. **42**, 196 (2010).

28. N. Nacereddine, M. Zelmat, S.S. Belaïfa, and M. Tridi, *Eng. Tech.* **2**, 145 (2005).

29. B. Mhamed, S. Abid, and F. Fnaiech, *Adv. Signal Process.* **1**, 1 (2012).

30. V.R. Rathod, R.S. Anand, and A. Ashok, *Nondestruct. Test. Eva.* **27**, 305 (2012).

31. *http://youtu.be/YXeo-6nE8t4*

32. E. Martínez, V. Carbonell, M. Flórez, and J. Amaya, *Comput. Appl. Eng. Ed.* 18, 757 (2010).