A VIRTUAL ENVIRONMENT FOR ENHANCING THE UNDERSTANDING OF TERNARY PHASE DIAGRAMS

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A VIRTUAL ENVIRONMENT FOR ENHANCING THE UNDERSTANDING OF TERNARY PHASE DIAGRAMS

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ABSTRACT

Materials and Mechanical Engineering students often find spatial visualization difficult. The problem appears in particular in the field of ternary phase diagrams. In order to improve the students' spatial skills in such a field, an interactive virtual application was developed using diverse commercial software: (i) 3DStudioMax© for designing the ternary equilibrium diagram and (ii) Quest3D© for giving the tool a more intuitive and ease-of-use character. The final design of the 3D virtual tool allows students to interact in real time with a ternary diagram, e.g. rotating views, changing the point of view, cutting the diagram revealing isothermal sections, observing hidden zones of the diagram by applying the transparency option, exploding view of phases and, so on.

Keywords: *engineering education, ternary phase diagram, 3D interactive virtual platform, three-dimensional viewing.*

INTRODUCTION

Phase transformations are important in a variety of industrial processes involving heat to thermochemical treatment of metal alloys. Therefore a deep knowledge of the phase diagrams (and associated microstructures) is required for students of mechanical and materials engineering. In particular, ternary phase diagrams (TPDs) are especially useful for analyzing countless metal alloys composed by a mixture of three elements, e.g., Mo-Si-B, as well as ceramic and inorganic glass systems composed of three compounds, e.g., NaO-CaO-SiO_2. All of which are interesting from the industrial point of view. From analysis of the appropriate TPDs, the final microstructure of the material is revealed and certain material/mechanical properties can be assessed. To this end, three-dimensional (3D) phase diagrams with a triangular base are commonly used, placing at the edges of the triangle the three elements comprising the metal alloy. Even so, for the sake of clarity, the TPD is simplified sometimes to a binary phase diagram (BPD) just considering an isoconcentration section of the TPD[1].

Most of the well-known book references commonly used in the teaching of *Materials*

Science and Engineering devote several chapters to this issue[2-5], mainly focusing on BPD of the most used alloys. However, due to the complexity of the analysis of phase changes in ternary alloys, most of the reference books do not include –or just give scarcely– any ideas about such issue[2-5]. Thus, students are not able to find any help for solving the *visualization problems*, which they must face when studying TPDs. The spatial visualization is really a serious problem that engineering students must overcome for carrying out tasks as future engineers[6]. In this sense, within the field of chemistry, some teachers have developed a virtual tool (VT) for enhancing the 3D understanding of the CO_2 and H_2O phase diagram[7]. However, although there are some examples of books analyzing TPDs of industrial alloys[8], it is not easy to find any reference in this field regarding a development of virtual tools for solving the students´ visualization problems.

According to previous studies[9-13], the spatial visualization skill can be improved by training. So, taking into account the current widespread use of didactic tools for the university teaching and their efficient results[14-17], an *interactive virtual tool* is developed in this paper in order to solve the visualization problems of the students. This VT allows them to develop a better and deeper understanding of the phase changes of ternary alloys by means of the study and analysis of virtual TPD. To achieve this goal, two different commercial software were used: (i) 3DStudioMax©, for the 3D modeling of diverse TPD of the most commonly used engineering alloys, and (ii) the software Quest3D©, for adding interactivity to the previously modeled virtual 3D phase diagrams. Interactivity is a key issue in virtual tools for increasing the students´ motivation[18-20].

DIDACTIC VIRTUAL TOOL

Two commercial software were used to develop the didactic VT. First, the modeling of the TPD was carried out by means of 3DStudioMax© software, to examine the different zones of the phase diagram. This way, a more realistic 3D spatial view can be viewed by changing the point of view or rotating the diagram instead of the common isometric view. However, the general-purpose software 3DstudioMax© is not able to be modified by untrained users and, consequently, a more simple user software, such as Quest3D©, was used for giving an intuitive character and interactivity to the didactic VT. The applications of Quest3D® were developed by connecting diverse functional components named "channels". The connection of the “channels” forms a tree structure, which represents the program

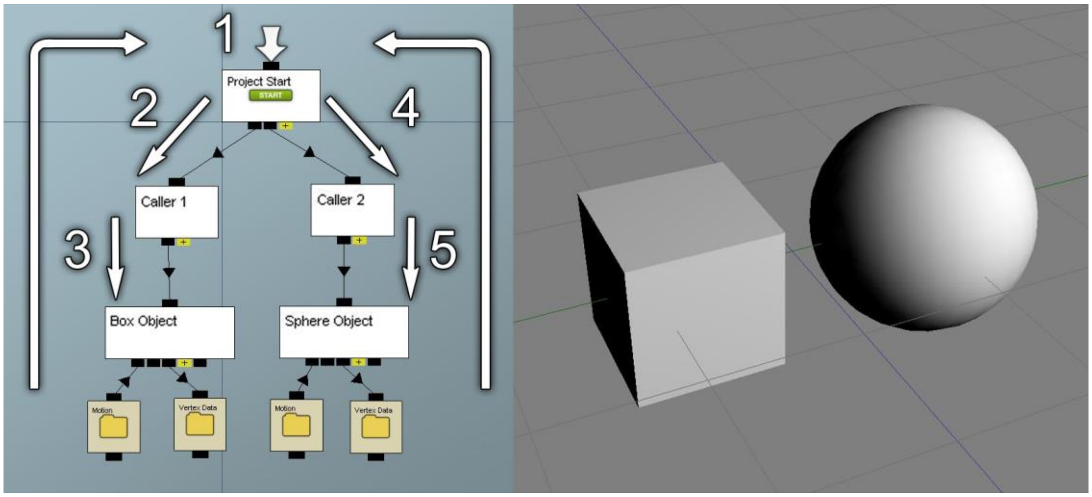


Figure 1. An example for understanding how channels of Quest3D® work.

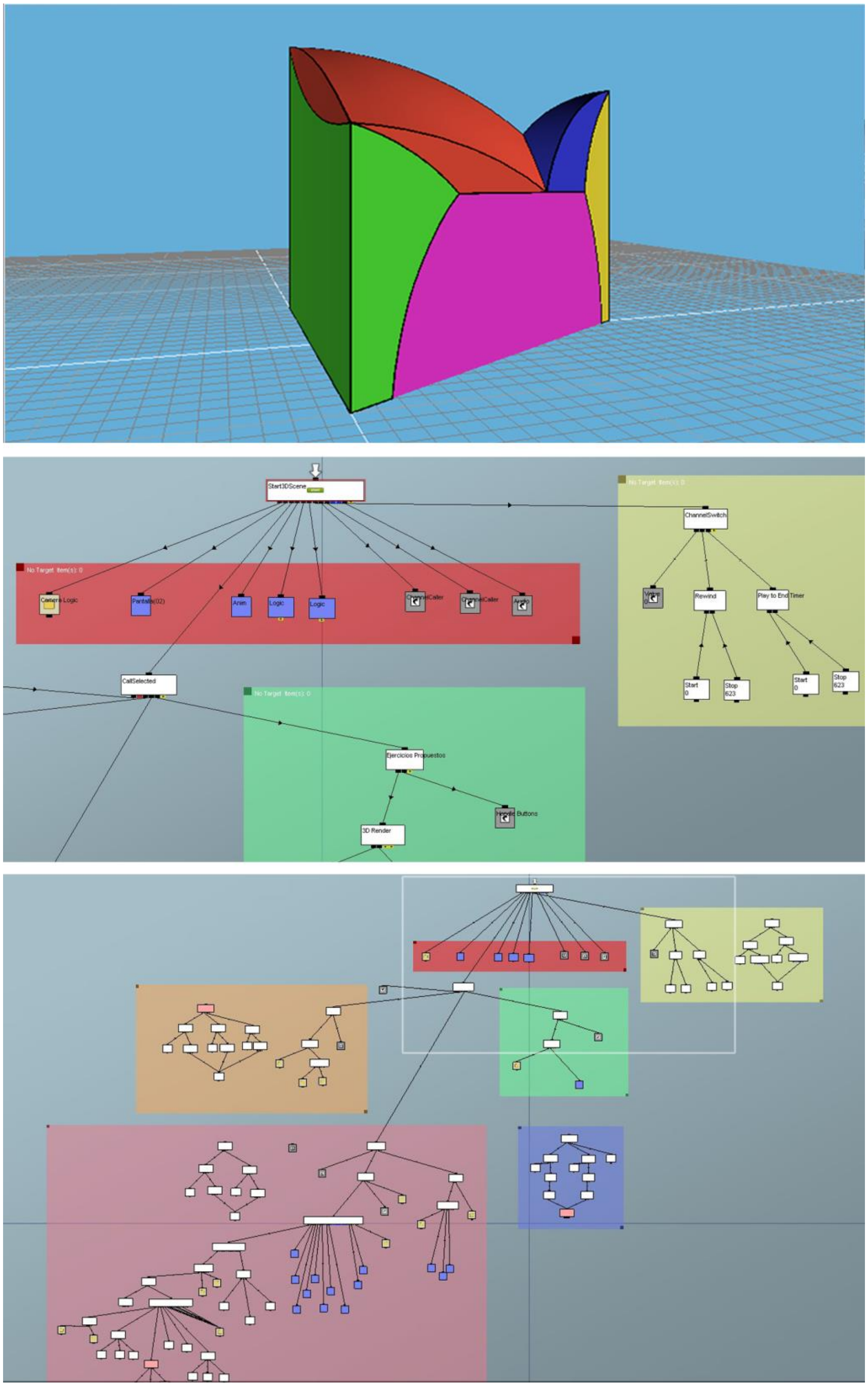


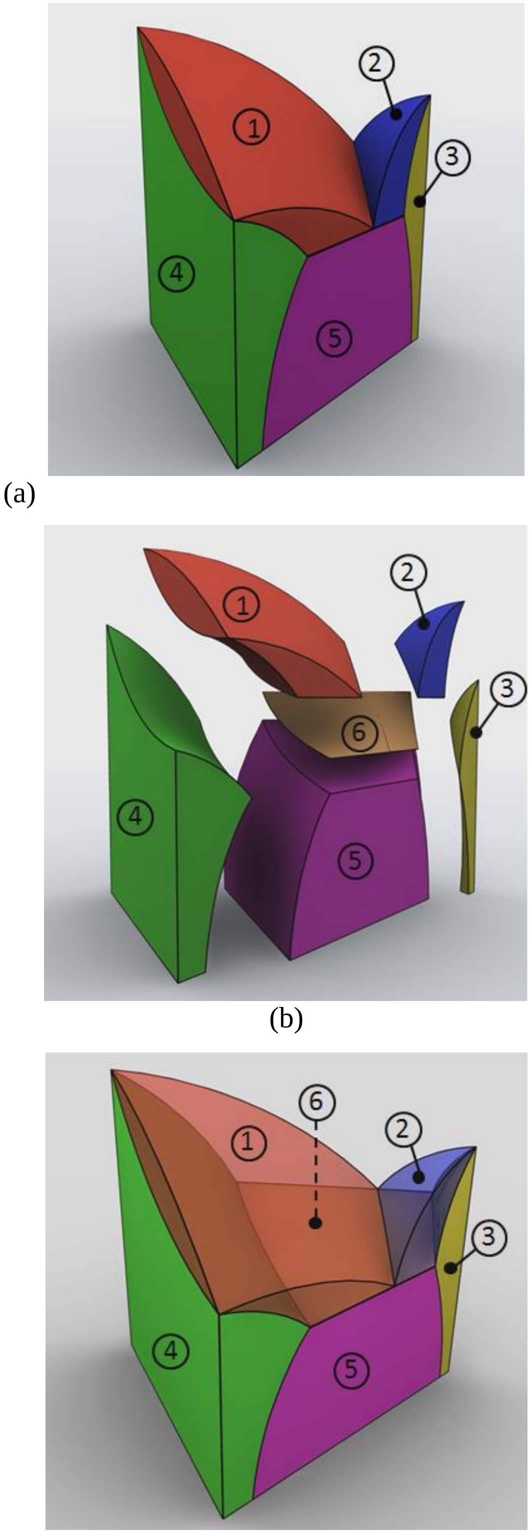
Figure 2. Screenshots of the programming environment of Quest3D® for the TPD VT.

structure. So, in Figure 1 *(page 94)* is shown how this tree structure works in one simple example for creating a box and a sphere. Channel callers work from left to right, therefore firstly the "Start Channel" invokes the left channel –Caller 1–. After that, the "Caller 1" channel invokes the hierarchy beneath it –Box Object–, which is a channel of type "3D Object". This channel displays a box on the screen (frame). After executing the hierarchy on the left hand side, the Start Channel continues with its second child –Caller 2–. So, this channel invokes its child "Sphere Object", creating the sphere showed on the screen (right hand of Figure 1). When the structure is completely executed, the program begins anew with the "Start Channel".

Although it is complicated to show a readable image of this process in the TPD VT, the general idea of this tree structure of channels is displayed in Figure 2 *(page 95)*. The surfaces which compose the 3D TPD were designed with Quest3D© as surfaces obtained from non-uniform B-spline curves (NURBS) previously modeled with 3DStudioMax©. Later, different colors and textures were linked to each surface allowing an easier identification (visualization) of the diverse TDP fields. In addition, Quest3D© allows obtaining an animated exploded view of the TPD in order to visualize the regions in a clearer way. Furthermore, this software combines a graphic engine with a development platform, which nowadays is used in diverse fields, such as product design, architecture, videogames, entertainment software and simulators from imported CAD models. The main characteristic of this software is the programming procedure, which allows –as the authors wished– real time interaction, completely different from the commonly used languages, e.g. C++. However, the advantages of using Quest3D© go further, since this software provides two key features : (i) the program code can be modified while the application is executed, making easier the correction of errors during programming, and besides (ii) the ultimate (final) version of the application can be published as an executable file. Consequently, the virtual TPD can be viewed using any web browser such as *Microsoft Internet Explorer* or *Firefox* by means of an *Active X* control. As an example, Figure 2 shows a TPD modeled with 3DStudioMax© where two of the elements of the alloy are fully soluble in the solid state (e.g. field 4 in Figure 3) and both are partially soluble with the third element. This is one of the most typical examples of an hypothetical TPD included in specialized texts[1,21-22], despite such a diagram do not corresponds with a real ternary alloy system with industrial interest.

For the sake of clarity, each phase, or phase mixture, e.g. region 5 is comprised of two phases, is identified in the plots of this paper by using arabic numeral notation. Besides, for a better understanding the *liquidus* phase was not included in this 3D TPD model, since such a phase has no industrial relevance. Figure 3b shows another interesting feature of 3DStudioMax© from the didactic point of view: the exploded view. This option allows a complete viewing of the phase fields and reveals those fields which are hidden by the outer fields, e.g. the field 6 shown in Figure 3b or the *solidus* and *solvus* lines which obviously are hidden in the assembled view (Figure 3a). The student can disassemble the virtual TPD and explore its geometry as wished. Hidden lines or fields are also visible by using the transparency option (Figure 3c). The VT allows the chance of identifying with a legend each one of the diverse fields which comprise the TPD. So, each color in the TPD corresponds with a solid solution (Greek alphabet letters) or a two-phase –or even three-phase– region[1,21-22] (Figure 4).

Rotation is another interesting feature of the VT from the didactic point of view since it enhances the students' self-learning by exploring and observing changes produced in the TPD. So, in the Figure 5 it is shown the virtual TPD from several points of view (rotation angles: 0º, 60º and 160º), corresponding to the angles that allows the visualization of the BPDs forming the TPD. Indeed, a TPD is just a composition of three BPD which are included in the outer faces of



(a)

(b)

(c)

Figure 3. TPD modeled with 3DStudioMax©: (a) general view, (b) exploded view, and (c) ternary diagram with the transparency option activated.

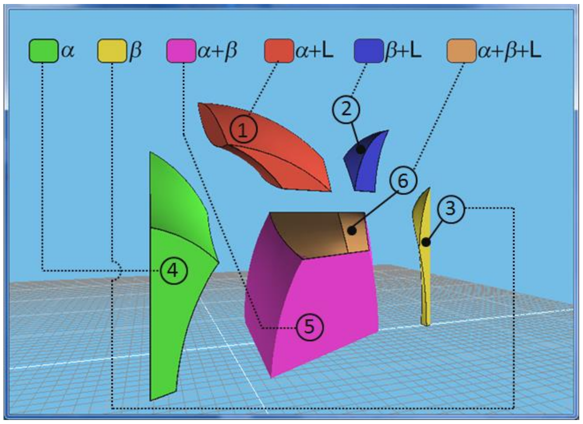
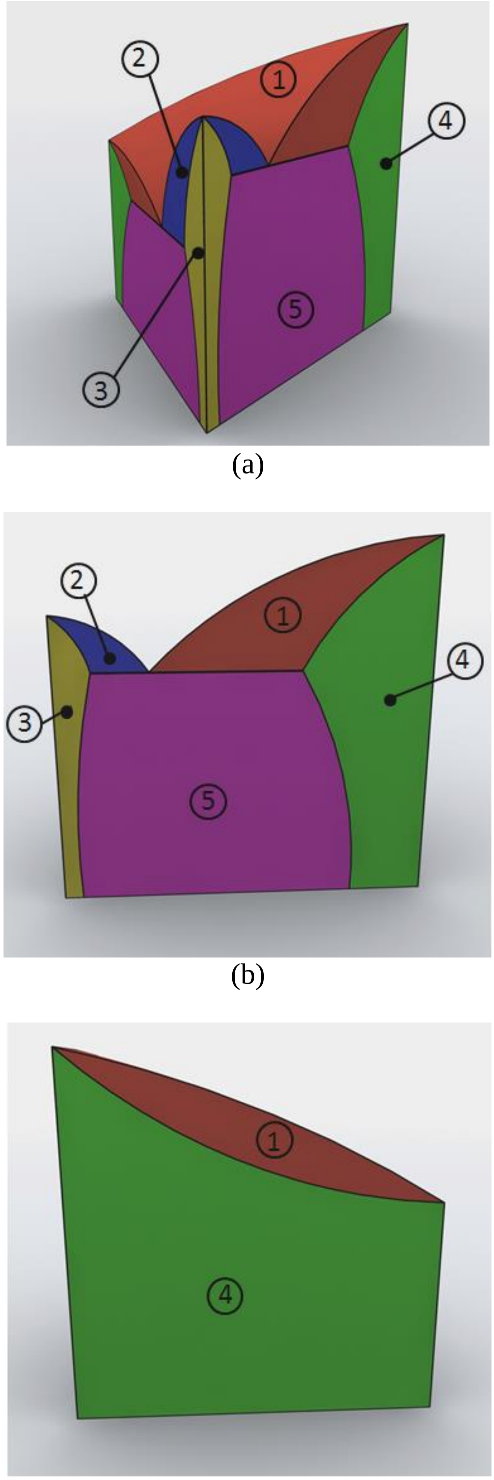


Figure 4. Exploded view including a legend in Quest3D® environment

the corresponding sides of the base triangle of the 3D TPD. The authors do not consider it really useful from a pure didactic point of view to include numerical values in the virtual TPD – elemental composition or temperature of a given industrial alloy–. Thus, the analysis of this TPD is completely general and the acquired knowledge is a good starting point for understanding any another industrial alloy used in industry. A common practice for analyzing TPDs is to study isothermal (for a given temperature) sections of the TPD. This way, the isothermal cross section (a simple equilateral triangle plot) reveals the different fields of the TPD. Taking this into account, such a feature was included in the proposed VT (Figure 6. Thus, the student is able to view directly the different isothermal layers of the diagram by means of modifying the temperature on the left side of the screen and observing the resulting cut on the right in real time (Figure 6).

The understanding of the teacher's explanation is enhanced by the direct viewing of the isothermal cuts. This way, Figure 6 shows the three representative isothermal sections of the virtual TPD analyzed in this paper (above maximum eutectic line temperature, at the binary eutectic line and below minimum eutectic line temperature). So, the designed VT is really useful when students must analyze isothermal cross sections of complex TPD. As an example, on one hand an isothermal cross section of the TPD above or below the

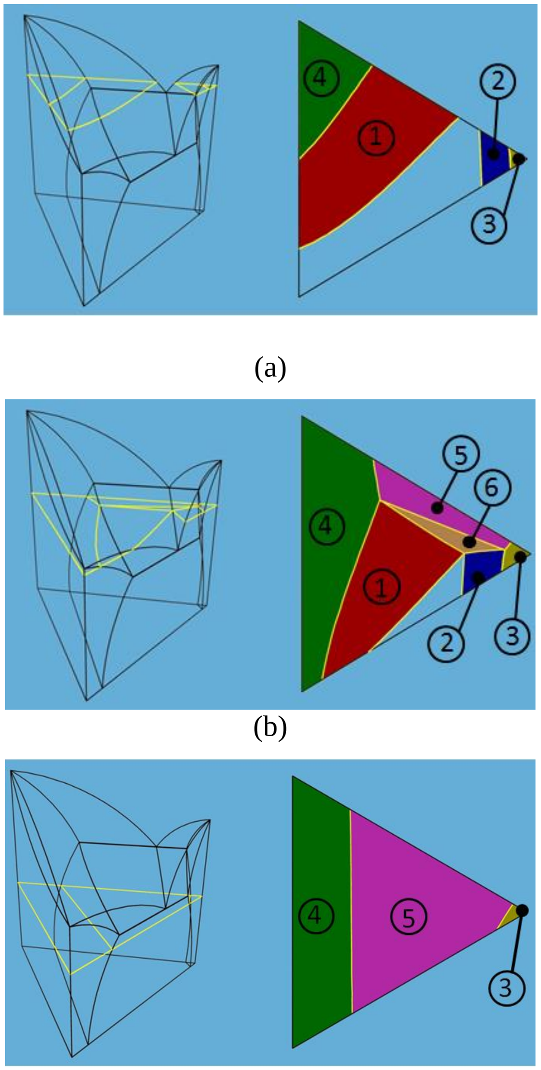


(a)

(b)

(c)

Figure 5. Rotation option applied to the TPD revealing the binary phase diagrams: (a) rotation angle 0º; (b) rotation angle 60º and (c) rotation angle 160º.



(a)

(b)

(c)

Figure 6. Isothermal sections using colored regions: (a) above maximum eutectic line temperature, (b) at the binary eutectic line, and (c) below minimum eutectic line temperature.

temperature corresponding to the binary eutectic line (Figures 6a and 6c) can be relatively easy to be visualized by students, on the other hand the isothermal cut of the TPD at the binary eutectic temperature is not so easy to be obtained and be understood by students (Figure 6b). So, the VT presented here allows a better understanding by showing the isothermal cut of the TPD for a given temperature, revealing the diverse phases which exhibit the alloy. The different zones of the isothermal cut can be colored (Figure 6) for obtaining a clearer identification of each phase, thereby increasing the students´ understanding.

STUDENTS' OPINION

In order to check the students' opinion in relation to the VT, a survey was carried out to students of diverse engineering degrees at the University of Salamanca: (i) Mechanical Engineering and (ii) Materials Engineering. Eighty students quantitatively rated different features of the presented didactic VT: (i) didactic quality, (ii) interactivity, (iii) ease of use, and (iv) motivation. This last feature of the VT focuses on encouraging students in order to continue using the tool itself. According to obtained results (Table 1 and Figure 7), students highly rated the didactic quality and their motivation when using the VT. Indeed, the low value of standard deviation (Table 1) suggests a low dispersion of the students' answers (from 9 to 10 for the first one feature –didactic quality–, and from 7 to 9 for the second one –motivation–). However, the students rating of interactivity and ease-of-use of the VT is slightly lower. Even so, the standard deviation does not reach a very high value (Table 1). This is due to answers were ranged from 6 to 9 for both cases. In the case of the interactivity, a possible explanation of its lower rating could be the need for constantly keeping updated the virtual resources for gaining the students´ attention[23]. The students are accustomed to using the most modern (and continuously upgraded) interactive applications not only for didactic purposes, such a virtual laboratories[24-28], but also for entertainment, such as videogames.

Table 1. Some examples of survey questions.

QUESTION	ARITHMETIC AVERAGE	STANDARD DEVIATION
Value from 1 to 10 the "Didactic Quality" of the TPDs virtual tool.	9.8	0.42
Value from 1 to 10 the "Interactivity" of the TPDs virtual tool.	7.5	0.88
Value from 1 to 10 the "easiness of use" of the TPDs virtual tool.	7.1	1.03
Value from 1 to 10 the "motivation" generating by the TPDs virtual tool.	8.8	0.51

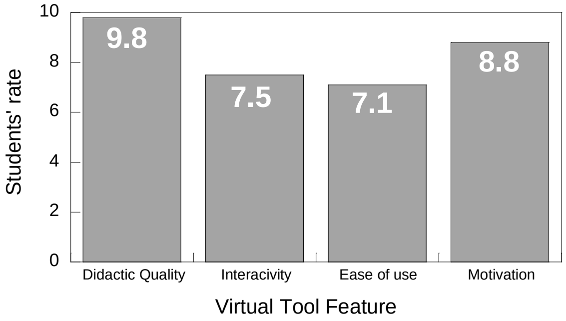


Figure 7. Students' valuation of the didactic virtual tool.

Even so, the use of the TPD VT in the classroom revealed two key issues in the students´ learning process: (i) the students´ questions during the class was notably reduced –probably due to the improvement of the spatial visualization of the TPD by using the VT, which allows a better understanding of TPD–; (ii) the key concepts were readily assimilated by students, as the answers to the final exam questions revealed; and (iii) students quickly understand the key TPD concepts due to the awakened interest in this topic when students use the VT.

Furthermore, students answered different questions related to the teaching methodology by use of the didactic VT described (Figure 8). On one hand, it seems that students consider this virtual application to be a very useful tool for learning TPD. Results reveal that students consider that the use of this VT requires a previous master class where the key concepts of TPD theory were covered (Figure 8a) in order to achieve a deep and effective understanding. On the other hand, students' opinion shows that the presented VT helps to solve the spatial visualization difficulties in the TPD comprehension (Figure 8b).

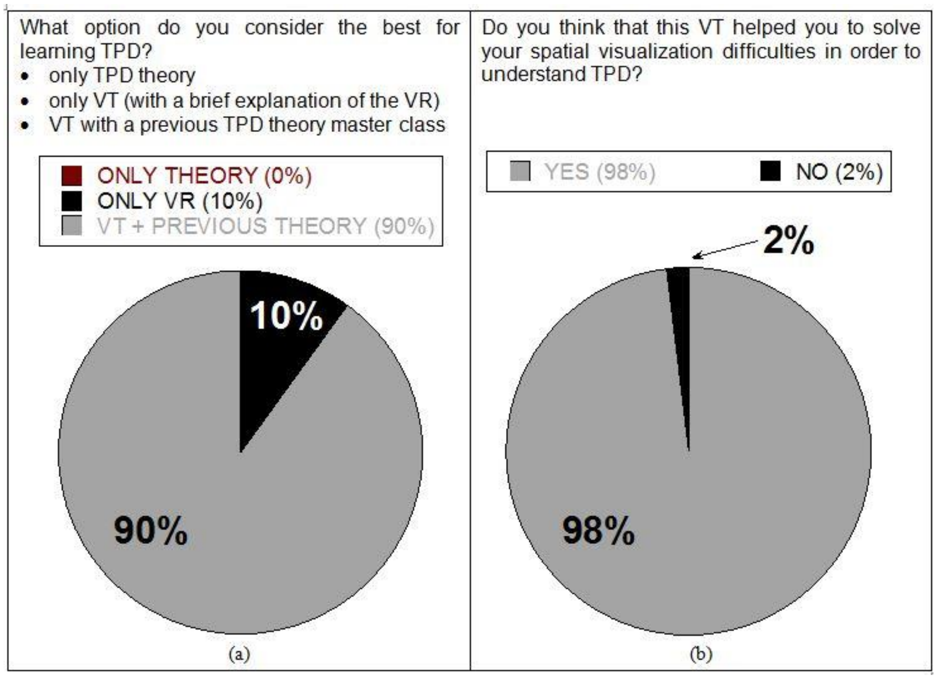


Figure 8. Students' answers with regard to: (a) the best methodology for learning TPD; (b) spatial visualization improvements by using the proposed VT.

CONCLUSIONS

Students' spatial visualization problems, such as the ones found in the learning of ternary phase diagrams, can be effectively solved by using virtual tools. The benefits of using an innovative virtual tool for leaning ternary phase diagrams in engineering degrees were shown in this paper. According to the students´ opinion, the proposed virtual application allows students to overcome their spatial visualization difficulties, thereby improving the understanding of the phase transformations which are produced during cooling in a complex ternary alloy. Also, the use of diverse options of the virtual tool (e.g. exploded view, rotate view, transparency, change of field colors, and so on) allows students a deeper understanding through a real time interaction with a ternary phase diagram. Thus, the spatial visualization problems associated with analyzing complex 3D shapes are practically removed by means of a self-learning process. However, according to the students' opinion, the use of virtual tools –as the one presented here– do not substitute but complement the master class where the key concepts about the ternary phase diagrams are discussed. Taking into account the constantly updating of virtual resources, students considered that an upgrade of the proposed virtual tool (with more modern interactivity options) should be necessary in the near future in order to maintain the same interest and motivation in the student body.

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