

Teaching Turbochargers via Computer Aided Design Software*

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A computer 3D model helps one to understand mechanical systems such as combustion engines. Because of its wide range of applications, engine knowledge is one of the main issues for a mechanical engineer. A turbocharger is a quite common engine component because it increases machine power. To show a turbocharger performance and its parts, we built a 3D model using Computer Aided Design software. We used a web-based learning management system to test the students. The results of a test and a survey showed that this educational method is successful. The 3D model generated could be used in other areas of knowledge such as engineering design and engineering graphics.

Keywords: 3D model; turbocharger; web-based learning system

1. INTRODUCTION

THE CONSTRUCTION of the European Higher Education and Research area leads to a student-centred educational model [1]. In order to create compatible educational models throughout Europe, the Bologna declaration [2] defined a 'credit' system; the 'European Credit Transfer and Accumulation System' (ECTS), based on the student workload, to achieve some competences. Competences define the contents of the matter [3]. In mechanical engineer education competences can be chosen from skills, concepts and the jobs that are more in demand for engineers.

The mechanical engineers' curricula include the concepts of heat engines, which are machines that transform energy by a compressible fluid cycle. Other internal combustion engines obtain mechanical energy from thermal energy. This is a very important because of its many applications, for example in electrical energy generation, transportation, farm machines, etc.

Over the last decades, computers and software have changed the engineering world. Consequently, these tools have been included in the engineering learning process. The use of animation as a teaching tool result in better learning and knowledge retention: Lowe [4] shows the cognitive potential advantages of animated graphics. Some scholars develop their own educational software that allows the construction of virtual simulations in order to improve the students' understanding of different concepts. For example, Karagülle [5] proposed using CAD software to model and simulate mechanical assemblies and, with the soft-

ware of Romeo and Padoan [6], students can model and simulate planar and spatial structures.

On the other hand, there are scholars who prefer the use of commercial software, because it has a general purpose and can be adapted to different learning needs. Flash animations have been used with good result as shown by Rubio *et al.* [7]. Gallis and Wang [8] used animations created by POV-ray (software to generate 3D animations) to explain introductory engineering concepts. They also proved, by a student survey, that animations help students to understand concepts, especially if such concepts are available on the web. Virtual simulations produced with *Computer Aided Engineering* CAE software reduce: cost, resources and time spent were compared with traditional real model and workshop practice. Based on this idea, Fu [9] proposed the use of ADAMS (commercial software to dynamic analysis) in mechanism teaching.

This work modelled and animated a turbocharger, a component that increases the power of a combustion engine. *Computer Aided Design* CAD commercial software is used because it helps to build solid components and assemblies, and also allows one to animate the system.

Engineering students are, in general, trained in different CAD commercial software, but what about using CAD software for teaching mechanical systems? Jensen and Pramono [10], and Fu [9] think these tools improve student self-learning because CAD software allows virtual experimentation. Another advantage is the increase in student motivation because difficult engineering problems [11], as in real world situations [12], can be solved with these tools.

The paper is arranged as follows. A real turbocharger (Fig. 1(a)) was used to obtain the CAD model (Fig. 1(b)) for the proposed learning

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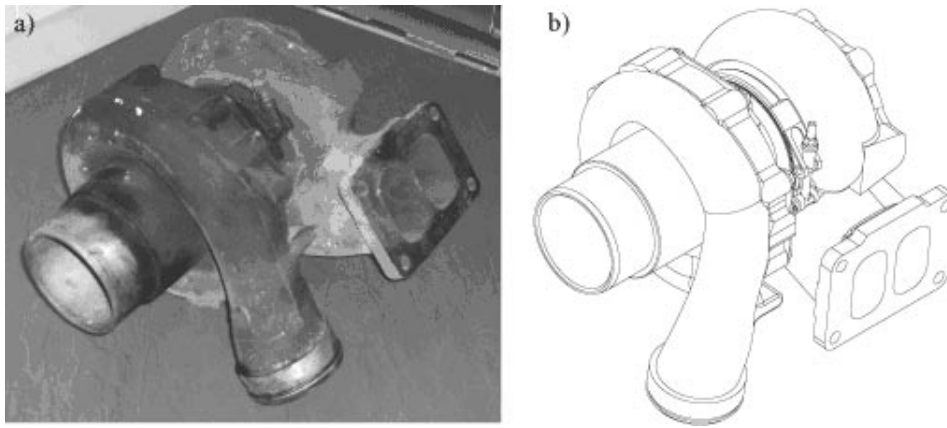


Fig. 1. Turbocharger: (a) real system; (b) 3D model.

method. The next section lays out the main characteristics of turbochargers. Then the main steps for building the mechanical system in SolidWorks (a commercial CAD software for designing and analysing solid models) is described. From the computer model, a 3D simulation (via CosmosMotion) is generated. The learning method based on the 3D model is described as well as the evaluation method based on Ilias, which is an open-source web-based learning management system [13]. Finally, the results and main conclusions are drawn in the last sections.

2. TURBOCHARGER

Turbocharging or supercharging systems are found in most alternative internal combustion engines. Their main function is to improve the engine power by compressing the intake air. This compression increases the amount of air that can be introduced into the cylinder, so more fuel can be burnt, giving a higher power output.

To compress the intake air, there are two main

systems: turbochargers and superchargers. In a turbocharger (Fig. 2), the turbine receives exhaust gases from the engine, causing the turbine wheel to rotate. This rotation drives the compressor, which delivers the ambient air into the intake manifold of the engine at higher pressure. As a result, a greater amount of air enters the cylinder. By contrast, a supercharger is mechanically driven by the engine's crankshaft via a belt (there is no turbine). Turbochargers are more efficient and common than superchargers, hence are of more interest to engineer students.

The main advantages of turbochargers are as follows.

- They increase the engine power (by between 30% and 40%). For an ordinary car, above 3000 rpm, the intake manifold pressure is more than 40 kPa (Fig. 3(a)), this is about 40% higher than in an atmospheric engine; hence the engine efficient is increased.
- They reduce engine weight and volume. For the same power, an atmospheric engine has more weight and volume than an engine with a turbocharger.

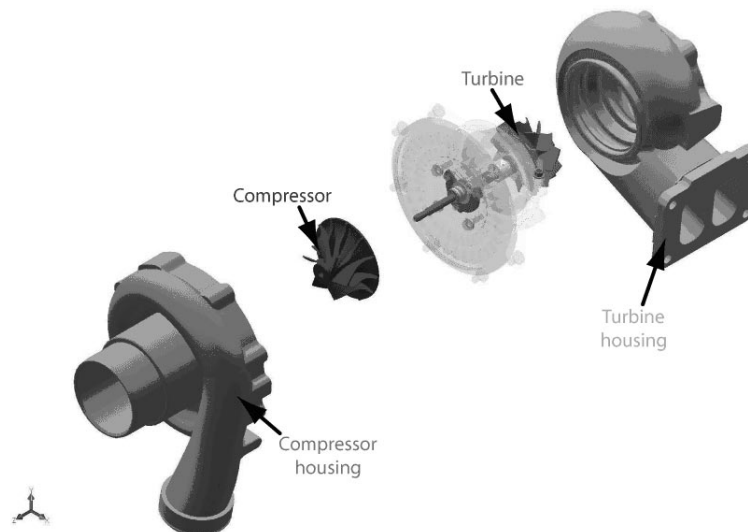


Fig. 2. Turbocharger main components.

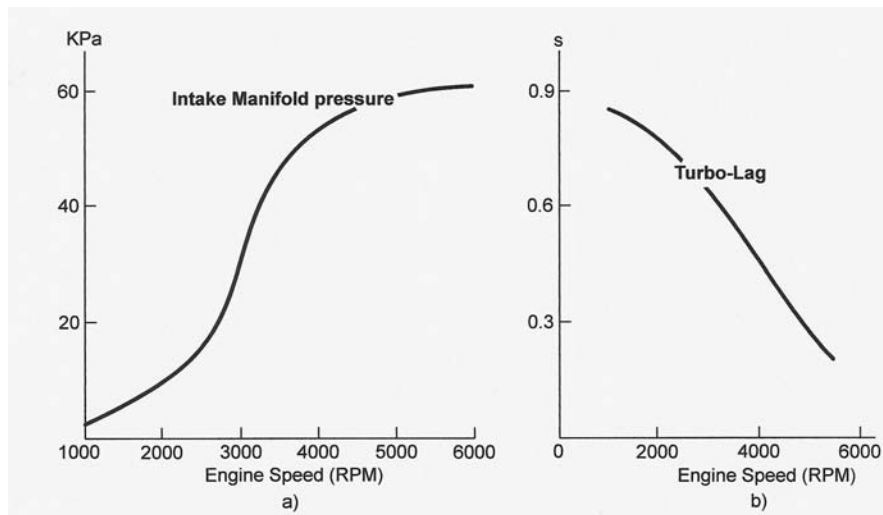


Fig. 3. (a) Intake manifold pressure and (b) Turbo-lag.

- They maintain the engine power with altitude (with respect to the sea level). Although altitude decreases the atmospheric pressure, the turbocharger maintains enough engine power because of the extra-intake pressure produced. This is a useful characteristic for aircraft engines.

The main disadvantages are as follows.

- Boost threshold. The turbine is moved by exhaust gases and thus if the engine speed is below a value called the boost threshold then there is insufficient exhaust gas to increase the manifold pressure, as Fig. 3(a) shows.
- Turbo-lag. After the throttle is opened, there is a time delay until the turbocharger turbine begins to move, this is the turbo-lag. There are many parameters that determine the turbo-lag: size, inertia, turbine efficiency, etc. Fig. 3(b) shows how the turbo-lag of a medium turbocharger depends on the engine speed.
- There is an increase in maintenance, because of the high temperature achieved.

This work proposes teaching about turbochargers using a 3D model that is based on a real Garret™ system (Fig. 1(a)). This equipment has two main components (Fig. 2): a turbine and a compressor linked by a shared axle. The turbine and compressor wheels are each contained within their own folded conical housing on opposite sides of the centre housing/hub rotating assembly. The housings, fitted around the compressor and turbine, collect and direct the gas flow through the wheels as they spin.

The previous definitions are based on and can be extended by the reference books of Challen and Baranescu [14], Heywood [15], and Watson [16].

3. CAD MODEL OF A TURBOCHARGER

SolidWorks is an easy-to-use CAD commercial software. It allows 3D model of a mechanical

system to be defined from its individual components and built by operations as extrusion, revolving and cutting, as described in the tutorial by Planchard and Planchard [17]. SolidWorks can animate the system and make static [18] and dynamic analyses [19]. These are the main steps in defining the 3D model of a turbocharger.

1. Measure the components of the real turbocharger. We measured the geometric dimensions of the real turbocharger parts.
2. Create 3D parts in SolidWorks. We used sketch tools for 2D drawings and operation tools to obtain 3D solids (Fig. 4).
3. Define the density of each part. Solidworks needs to know the density, inertia and centre of gravity to make a realistic animation. If we

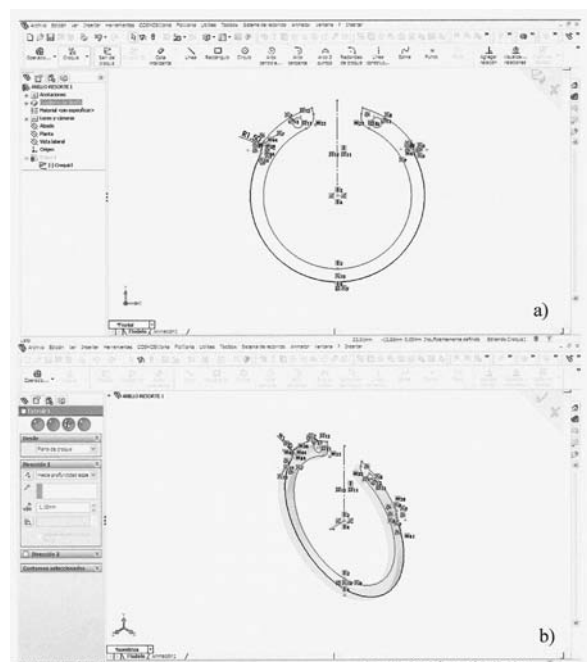


Fig. 4. Example model of a 3D component: (a) sketch. (b) extrude operation.

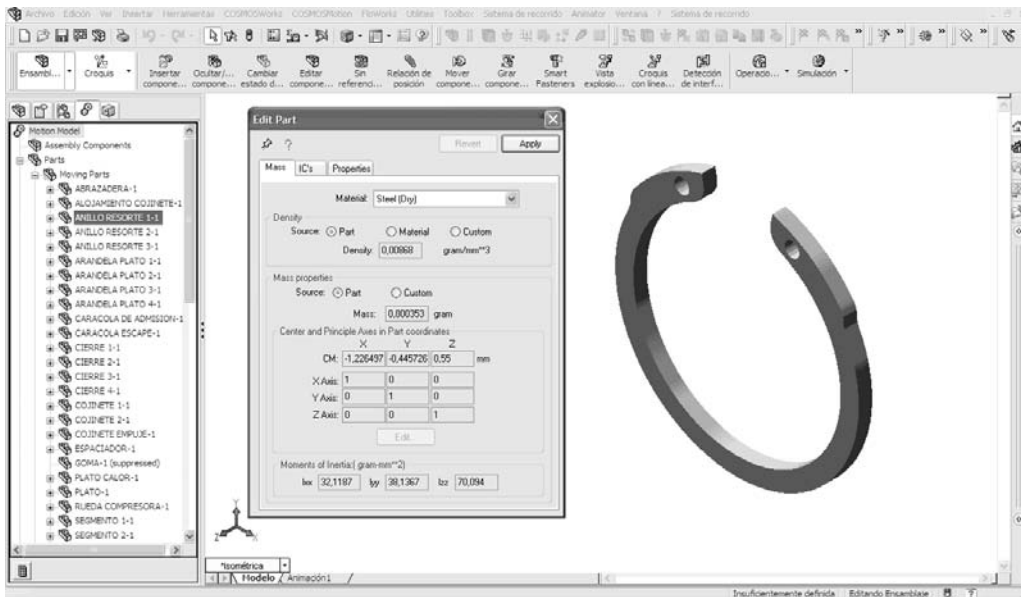


Fig. 5. Definition of physical properties.

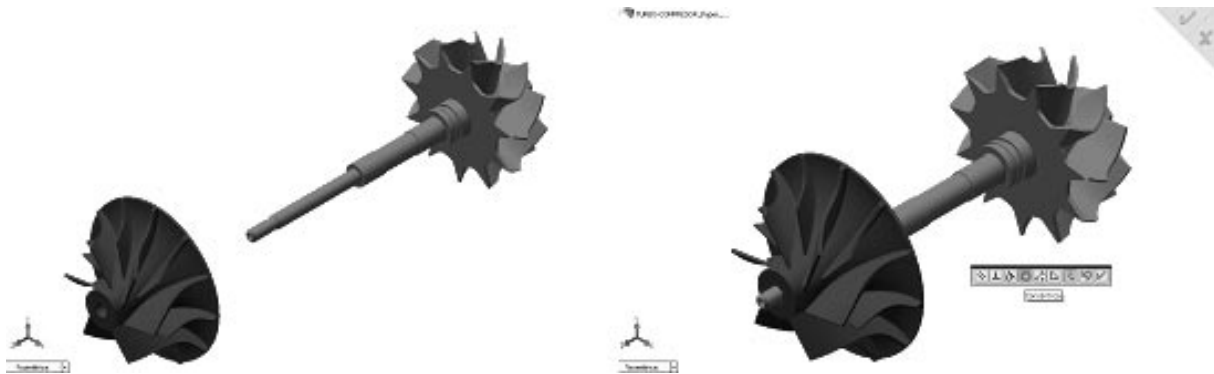


Fig. 6. Example of assembly components: turbine, axel and compressor.

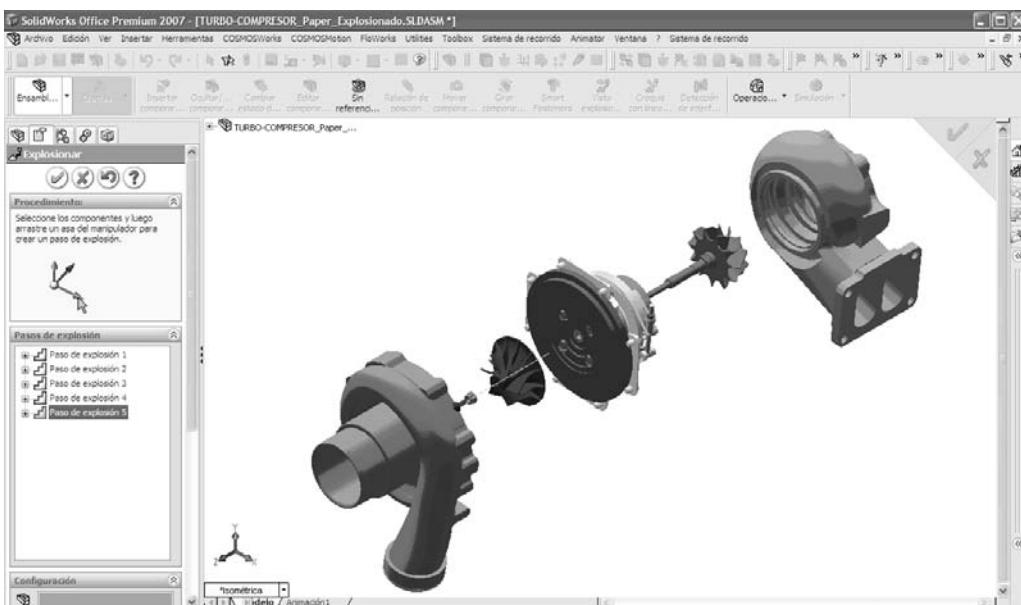


Fig. 7. Exploded view.

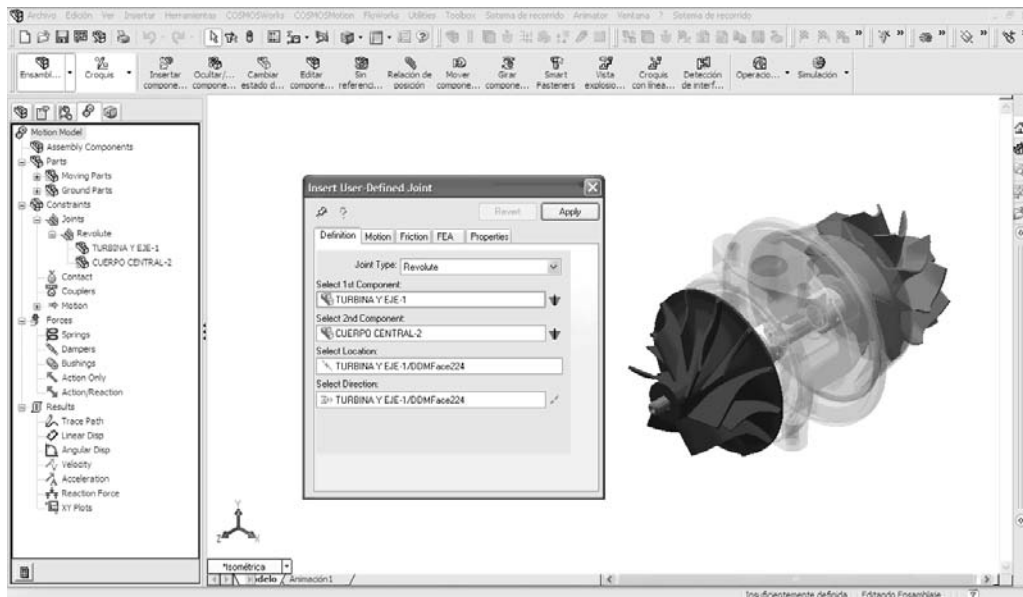


Fig. 8. Definitions of joints and movements.

define the density, the software can compute the rest of physical properties needed. We measured the mass of the components and used Solidworks to compute their volumes (Fig. 5), with these quantities we easily obtained the density.

4. Assemble 3D parts to obtain the mechanical system (Fig. 6). We added geometric relations-constraints between parts.
5. Generate an explode view to identify the main parts assembled. We used Solidworks tools, as shown in Fig. 7.

4. ANIMATION AND SIMULATION

The previous section is an interesting exercise for training CAD students in commercial software using a real design problem. Moreover, it can be used to identify the main components of a turbocharger in a heat engines course. An animation of the assembly also shows the relative motion between components. To model the real kinematics and performance, the designer needs a simulation that considers the physical properties of each part.

We use CosmosMotion, a SolidWork module, to study the movement of a mechanical system. Motion simulation provides complete and quantitative information about the kinematics (position, velocity and acceleration), and the dynamics (joint reactions, inertial forces and power requirements) of all the components of a moving mechanism. As a result of this simulation we also obtain an animation of the system. The main steps for the simulation are as follows.

1. Define the ground and moving parts (Fig. 8).
2. Add constraints between parts and define exter-

nal forces. This step is necessary when there is no geometric relation between parts.

5. TEACHING METHODOLOGY

This study included 57 undergraduate mechanical engineers at University of Jaén. The students were enrolled in the Heat Engines course in the Spring semester of 2008. One of the main problems with methodologies based on new technologies is in evaluating the improvement in the learning process. We created two groups to evaluate the success of the method. We used traditional teaching methods with group I (28 students), and our method based on CAD 3D model with group II (29 students). These are the main steps followed in the learning process for groups I and II.

5.1 Stages group I

- Classical theory session. We introduced the performance, main components, types and applications of turbochargers. Time estimated: 2 hours.
- Assessment. Students answered a list of questions about their acquired knowledge (Table 1). We use Ilias web learning system to test our

Table 1. Test questions.

All questions have the same value → 1.25 points

1. What fluid goes through the compressor?
2. How is the turbine moved?
3. Identify the main parts of a turbocharger
4. What is the turbine and compressor housing function?
5. Identify the turbocharger ground parts.
6. What kinds of stress appear in the turbocharger components?
7. What is the target of a turbocharger?
8. A turbocharger can be applied to diesel and gasoline engines. True or false?

students (Fig. 9). Ilias allows such a creation and checking test on line. We can also define the date, hour and time for the test. Time estimated: 1/2 hour.

5.2 Stages group II

Animation. We used 3D computer model in order to visualize the main mechanical equipment parts via an explode view, and to show its perfor-

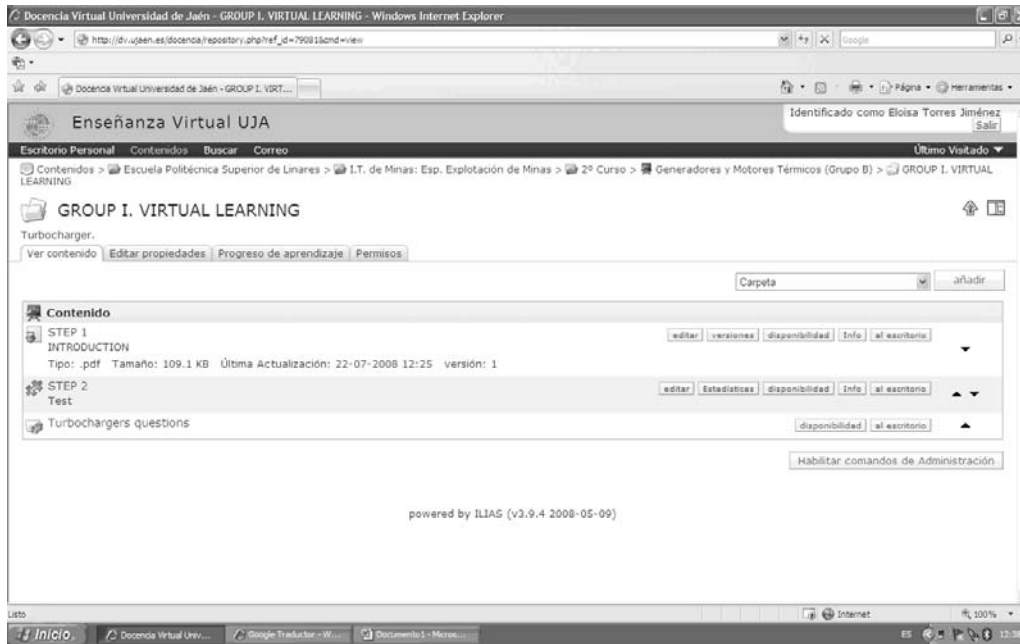


Fig. 9. Group I. Ilias information and assessment.

Table 2. Survey questions

Survey questions	Disagree	Agree
1. Do you prefer classical or animation teaching session?	1 2 3 4 5	
2. Is the turbocharger an important issue for a mechanical engineer?	1 2 3 4 5	
3. Do animations help us to understand mechanical systems such as a turbocharger?	1 2 3 4 5	
4. If you can see an animation of a mechanical system, do you think you need less time to understand its performance?	1 2 3 4 5	

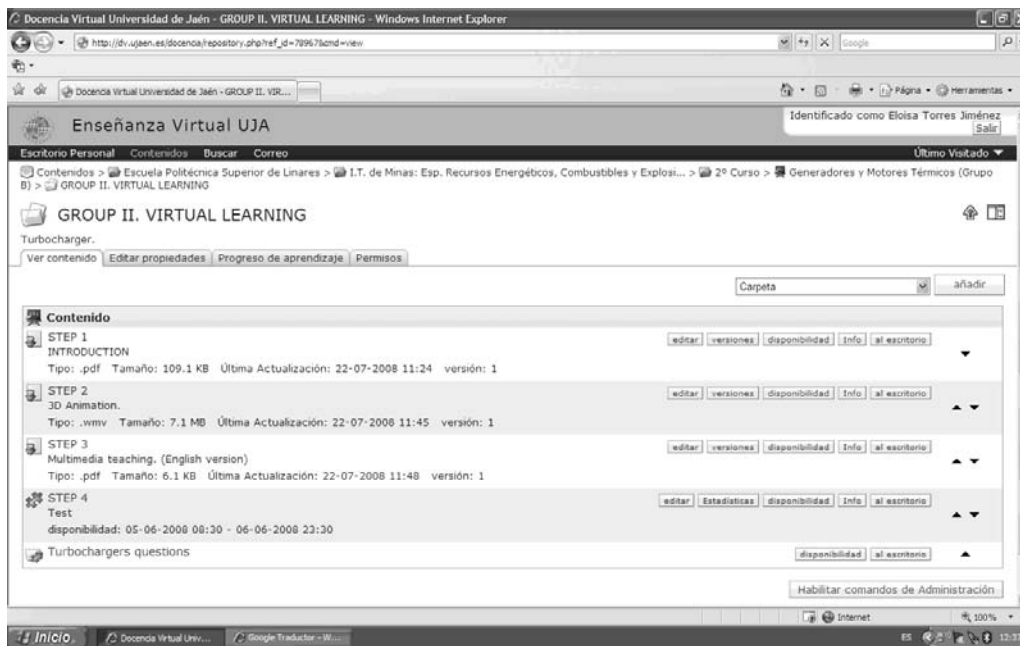


Fig. 10. Group II. Ilias information and assessment.

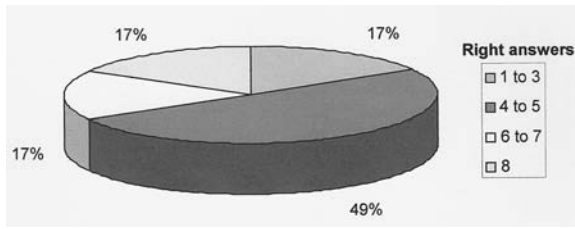


Fig. 11. Group I. Distribution of right answers.

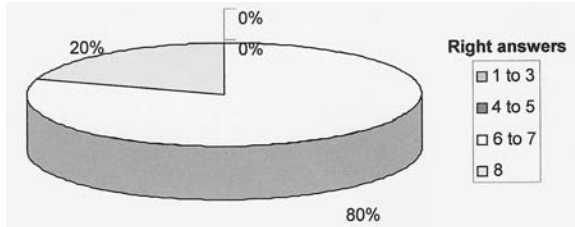


Fig. 12. Group II. Distribution of right answers.

mance via an animation. We completed the animation with a theoretical talk. Time estimated: 1 hour.

Assessment. The students answered the same list of questions (Table 1) as group I, and also through Ilias (Fig. 10). Time estimated: 1/2 hour.

Survey. We invited students to fill in an opinion survey about this learning method (Table 2). Time estimated: 1/2 hour.

5.3 Stage common for group I and II:

We showed the real GarrettTM turbocharger in a heat engine laboratory. As the equipment is assembled, it is very difficult for the students to identify the internal parts and to understand the system performance. Time estimated: 1/2 hour.

6. RESULTS AND DISCUSSIONS

In order to check the success of the teaching method, we analysed the results of the test and survey stages followed above. Ilias provides the information in Excel format. Figures 11–15 show the main results:

- Group II students had better test results than group I (Figs 11 and 12).
 - The 83% of Group I answered more than four questions correctly. Over 50% answered from four to five questions correctly.
 - All students of group II correctly answered more than four questions. Over 80% answered from six to seven questions correctly.
- Questions number 2, 6 and 8 (Table 1) were difficult for the students (Figs 13 and 14).
 - Group I have more problems than group II.
 - Results are more uniform for group II.
- The mean time taken to answer was 15 minutes for group II. It was less than the initial estimated

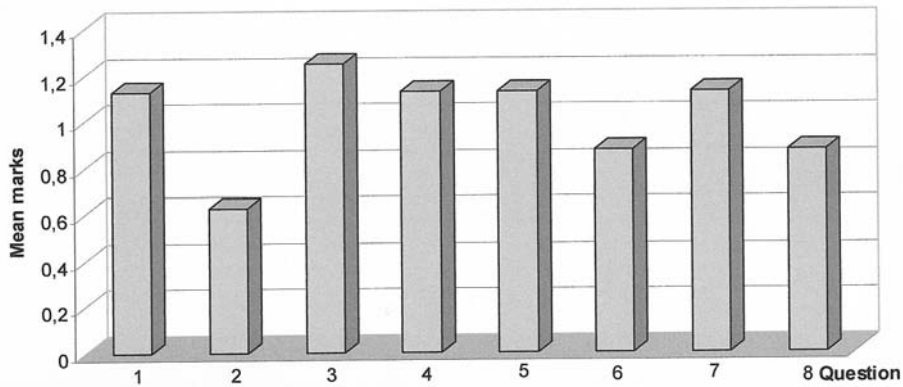


Fig. 13. Group I. Questions mean marks.

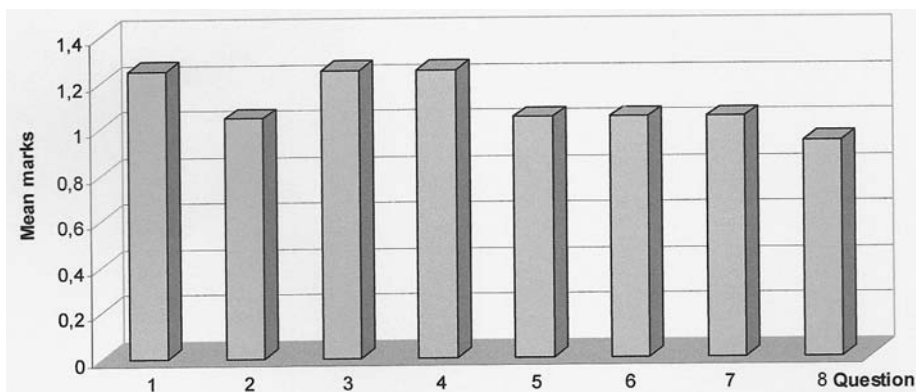


Fig. 14. Group II. Questions mean marks.

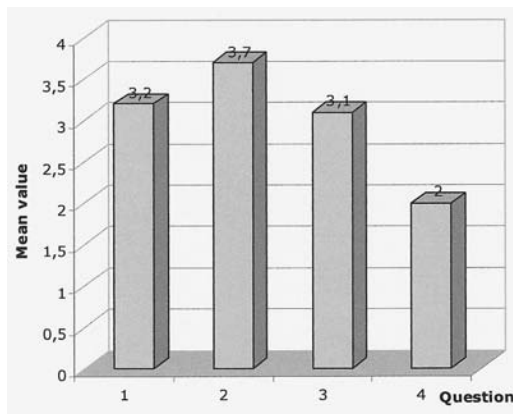


Fig. 15. Survey mean results.

time. Group I spent near 30 minutes to complete the test.

- The opinion survey (Table 2, Fig. 15) suggests that the methodology based on animations increases students motivation.

As results show, the teaching methodology improves students learning significantly. Both group II and group I had problems with questions 6 and 8, because the animation didn't help with the solution. In spite of this, Figs 13 and 14. suggest better results for group II because the animation increases the students' interest in turbochargers. Also, some pupils made the comment that the

experience was entertaining as it was unlike the usual learning sessions.

7. CONCLUSIONS

The tools provided by CAD commercial software can be very useful for engineers' education. The 3D computer models are a great help in teaching in technology courses. In these courses, the student must identify the main parts and performance of different pieces of equipment that are commonly assembly. Therefore, a virtual exploded view and an animation are important visualization tools.

In this paper, a 3D mechanical system was modelled and used in a heat engine course. We have explained the main steps for building a turbocharger computer model, how we have used 3D models animations in classroom, and the method of evaluating our students' learning.

To demonstrate the success of the proposed teaching method some tools are needed. The survey and assessment results show that teaching strategies, based on a visual thinking system, result in better learning and retention.

As a future work we aim to extend this methodology to other mechanical components of an internal combustion engine. Building these 3D models could also be proposed as an activity for engineer design students.

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REFERENCES

1. M. Contero, F. Naya, P. Company and J. L. P. Saorin, Learning support tools for developing spatial abilities in engineering design, *International Journal of Engineering Education* **22**(3), 2007, pp. 470–477.
2. The Bologna Process, Towards the European Higher Education Area: ec.europa.eu/education/higher-education/doc1290_en.htm
3. *Tuning Educational Structures in Europe*, University of Deusto and University of Groningen, 2003.
4. R. Lowe, Beyond 'eye-candy': Improving learning with animations, Apple University Consortium. Available from: auc.uow.edu.au/conf/conf01/downloads/AUC2001_Lowe.pdf, 2001.
5. H. Karagülle, A new approach for engineering education, *Proceedings of the 28th International Symposium on Engineering Education*, G. Saglamer, A. Melezinek and S. Incecik (eds), Leuchterturm-Verlag, Germany, 1999.
6. F. Romeo, G. Padoan and J. Truss, A CAD-oriented educational open-source software for static analysis of truss-type structures, *Computer Applications in Engineering Education*, **16**(4), 2008, pp. 280–288.
7. R. Rubio, J. Suárez, R. Gallego, S. Martín and S. Morán, Interactive Multimedia Animation with Macromedia Flash in Descriptive Geometry Teaching. *Computers & Education* **49**, 2007, pp. 615–639.
8. M. R. Gallis and P. Wang, Introduction animations for introductory courses. *CiteSeerX-Scientific Literature Digital Library and Search Engine*. Available from: www.scientificcommons.org/42530126, 2008.
9. T. T. Fu, Applications of computer simulation in mechanism teaching, *Computer Applications in Engineering Education*, **11**(3), 2003, pp. 156–165.
10. D. Jensen and E. Pramono, Method for teaching finite elements which combines the advantages of commercial pre and post processing with student-written software, *Computer Applications in Engineering Education*, **6**(2), 1998, pp. 105–114.
11. A. Aminmansour, Utilizing the best of today's technologies to better educate engineers of tomorrow, *Computer Applications in Engineering Education*, **4**(1), 1996, pp. 79–84.
12. G. R. Miller and S. C. Cooper, Something old, something new: Integrating engineering practice into the teaching of engineering mechanics, *Journal of Engineering Education*, April, 1995, pp. 105–115.
13. ILIAS Learning Management: www.ilias.de

14. B. Challen and R. Baranescu, *Diesel Engine. Reference Book*, Butterworth Heinemann, 1999.
15. J. B. Heywood, *Internal Combustion Engine Fundamentals*, McGraw-Hill International Editions, 1988.
16. N. Watson, *Turbocharging. The Internal Combustion Engine*, MacMillan Education, 1992.
17. D. C. Planchard and M. P. Planchard, *SolidWorks 2006 Tutorial. A Step-by-step Project Based Approach Utilizing 3D Solid Modelling*, SDC Publications, 2006.
18. J. R. Steffen, *Analysis of Machine Elements using COSMOSWorks Professional*, SDC Publications, (2006).
19. Understanding motion simulation, *White paper SolidWorks Corporation*, 2006.

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