5 EXPERIENCES ABOUT TEACHING THE USE OF TOOLS IN AN ENGINEERING DESIGN COURSE

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Engineering design is an area of specialisation with the School of Industrial Engineering, Technical University of Catalonia (UPC). One of the courses of this specialisation is Product Engineering and Technical Systems I (EPISTI). In this course, students learn the basics of several tools employed in product engineering design and apply those to the design of products. At the end of the course, students are required to prepare and present a basic project. An example of these projects is included in the paper.

In the academic years 2006-07 and 2007-08, more design tools were explored than in previous years. The results of this experience and some future changes are discussed.

Keywords: Course Structure, Engineering Design Tools, Groupwork Homogeneity.

1. INTRODUCTION

Engineering design is an area of specialisation offered in the last three years of the industrial engineering degree at the Technical University of Catalonia (UPC).

Among the courses included in the Engineering Design curriculum, we can find Product Engineering and Technical Systems I (EPISTI),[1] which is taught in the second year of the specialisation (8^{th} semester).

EPISTI was first taught in the academic year 1997-98 by the first author above. Due to the increase in enrollments in this course, a PhD student (O. Tomico) was hired as an assistant professor for the academic year 2005-06. The second author above started teaching EPISTI in 2006.

In EPISTI students familiarise themselves with several product design tools, and then are required to design an innovative product. They work in teams of 5 to 6 students and each team does a different job.

Students present their work orally in the middle and at the end of course. Also at the end of the course they must submit an assignment as their main final work. This is called “pre-project” since it is a basic project and is a preparation for the final project which must be presented at the end of the degree. The total number of students in the 2007-08 course was 38, 37 of whom attended classes regularly.

1.1. Class structure

EPISTI classes last two hours, with two sessions per week from February to June (spring semester) and are given by two instructors. Theory is taught during the first half of the class while the second half is devoted to student group work, with the instructors acting as tutors. Both instructors are acquainted with all the groups’ work, but each team is supervised by one single professor.

1.2. Evaluation system

The following criteria count towards the final mark:

- Individual marks: class attendance, oral presentation of first work -in the middle and at the end of the course- and class assignments.
- Group marks; two oral presentations, class assignments and final written assignment.
- Written examination, if necessary (5 students in the academic year 2007–08).
- Rounding of decimals of the final mark (only in a few cases).

These criteria, the most important of which is the final written assignment, have different values. However, if a student needs to sit a final examination, this test is given the most weight.

1.3. Group projects

Students are required to create a new product or improve an existing one.

In the 2007-08 course, the projects presented were:

- LED street lamp. This project is a continuation of previous work, but with a different structure.
- Individual small boat "Overwater". New product.
- Improved hand dryer.
- Wheelchair lift for one step. New solution for a wheelchair.
- Walk electricity generator. New product.
- Water flow controller for gymnasiums. New product.
- Steam cleaner. Improved product with a new function.

All projects had a certain degree of invention or innovation, and although basic, they included detailed descriptions of some parts.

The course topics included in Section 2.1. must be present in the "pre-projects".

2. COURSE STRUCTURE

Students are expected to become familiar with engineering design tools. The final work consists in the submission of a basic project which must include objectives, state-of-the-art, alternative solutions, planning and cost of product designs.

During the academic year 2006–07, one of the instructors (first author above) suggested that more design tools should be explored in future courses. The question arose whether it was more beneficial to students to gain deeper knowledge of only a few tools or superficial knowledge of many tools. Finally, the second option was chosen.

Below are the topics and the results of this new experience.

2.1. Topics of 2006–07 and 2007–08 Courses

- **Objectives**:
  At the beginning of the course the general goals of creation or improvement of products are defined.
- **First ideas towards a solution:**
  Creativity techniques, like brainstorming, are used in this section to find basic ideas for solutions.

- **Functional analysis:**
  In order to create or adapt products capable of meeting user needs, the latter are analysed, and then a list of functions to be accomplished by products is created by the student groups using the Sequential Analysis Functional Elements (SAFE) technique.
  Functions are compared with a two by two matrix, and a list in order of importance with relative values of the functions is made. Subsequently, a Pareto diagram is used to visualise these matrix-valued functions and the rule 20/80 is applied, that is, concentrating the design efforts on 20% of the most important functions ensures 80% of the functional expectations of the product.

The functional analysis is completed by arranging the functions according to the Functional Analysis System Technique (FAST), which gives an ordered graphic of functions.

- **State-of-the-art:**
  The state-of-the-art is reviewed by finding similarities between commercial products and exploring patent databases.
- **Product design evolution:**
  By accomplishing the above tasks, different aspects of products are defined in general terms while functional requirements are addressed. Simultaneously, any observed advantages and disadvantages of products are analysed.
- **TRIZ:**
  The Theory of Inventive Problem Solving (TRIZ) is used to inspire the best solutions to engineering contradictions of products. This methodology seems a complex one for students who look at it for the first time, but it has proved a useful tool in the idea-generating process.
- **General criteria of Ecodesign and MET matrix:**
  In order to obtain an ecological improvement of designs, less impacting materials are chosen. In addition, these are homogenised and less energy-consuming processes are preferred. These basic strategies of Ecodesign are complemented by a Materials, Energies and Toxics (MET) matrix which classifies and visualises possible environmental impacts during the life cycle of products.
- **Risk analysis:**
  Potential risks caused by the use of certain products are analysed with a cause-effect diagram, i.e. Ishikawa diagram, to make them safer. The possibility of failure of products is estimated and causes are investigated to reduce possible future mistakes.
  Additionally, the Evolution Tree Analysis (ETA) is applied to predict incremental effects.
  In order to increase the reliability of products and predict potential failures of components, the Failure Tree Analysis (FTA) is used in the design stage. Preventive measures can thus be taken.
  A risk-based decision-making analysis tool (HAZOP) for risk identification is also useful in the design stage to evaluate variable deviations during the product-making process. Guide words applied to deviations help to determine possible causes and effects and to think of actions to be performed.
  Failure Mode Effect Analysis (FMEA) also allows avoiding potential failures of products. The occurrence, importance and non-detection probability of the effects of such failures are subjectively assessed. The product of these three factors gives a risk priority index. The goal is then to reduce this index by redesigning the product in order to make it safer.
- **DFA:**
  The Design For Assembly (DFA) technique is applied to some specific parts of products which are designed in detail. Simplification of some parts and analysis of manufacturing time can result in an improved design in terms of time (and cost) of the manufacturing process.
- **Planning and costs:**
  The tasks involved in the project are arranged by means of a Gantt chart. The economic costs of the design are in relation to this arrangement and the cost of materials from the beginning to the end of the manufacturing process.
- **Plans:**
  The design plans (with different levels of detail for different parts of the product) must be submitted along with the project documentation.

2.2. Differences in Course Topics Between the 2006-07 and 2007-08 Courses and Previous Years

Topics in previous years (1997-98 to 2005-06) were organised similarly to the two last years (2006-07-08), i.e. with a pre-project structure. The engineering design tools presented were:[3] Functional Analysis System Technique (FAST); Value Analysis; Quality Function Deployment (QFD); Failure

Tree Analysis (FTA); Feasibility, safety, reliability and maintenance; Design For Assembly (DFA); Design for dismantling and recycling; Industrial property (patents); and Design communication.

One of the changes introduced concerned the Quality Function Deployment (QFD) tool, which used to be explained by a professor of a different area of specialisation in previous years. This tool had to be eventually eliminated from the list of contents. On the other hand, Ecodesign strategies were included.

In the academic year 2006-07 some new tools were introduced: Pareto diagram; Theory of Inventive Problem Solving (TRIZ); Cause-effect diagram (Ishikawa diagram); Evolution Tree Analysis (ETA); Risk-based decision-making guidelines (HAZOP), and Failure Mode Effect Analysis (FMEA).

Other tools include SAFE analysis for functional analysis, and Materials Energies and Toxics (MET) matrix for ecodesign.

All these tools are described in different books or papers, and can also be found on the Internet.[4] Some, such as TRIZ and MET matrix, are explained at length in other courses.[5]

3. RESULTS

All student groups of the academic years 2006-07 and 2007-08 completed the pre-project work with reasonably good results and the products included some new design feature. Moreover, some groups provide some interesting new engineering design solutions.

A loss of homogeneous quality of the works presented in the 2006-07 and 2007-08 courses was observed compared with previous years. This could be due to the pressure under which students have had to perform in recent years. Workload is divided in such a way that each student in the group work on several tools, and finally individual work is aggregated into the "pre-project". Time pressure implies a lack of homogeneity of work quality because of the difference in quality of individual work.

All students learned about and used more design tools, but perhaps not to the same degree. On the positive side is the fact that more tools were examined and final assignments were more complete.

Some tools were used when designs were not mature yet. In these cases, groups assessed possible virtual scenarios subjectively, and thus had the chance to apply these tools in the conceptual design phase. Final designs were then made and projects of new products were finished. Only a few iterations were applied to designs because of lack of time.

3.1. Example

An example of a final product is the individual small boat (see Figures 1 and 2). A person drives the boat with his/her legs and feet by means of a stepper mechanism with two propelling wheels. A collapsible handlebar-rudder is also provided.

The design evolves from the initial idea, namely to walk over the water. A large number of draft designs were made.

Now follows an example of how functional analysis and TRIZ were applied in this final work:

Functional analysis: 30 functionalities were defined. Some of the most important are to bear the weight of an adult; to have a safe structure; to have floatability; to be safe for swimmers; to have a good propulsion system, etc.

TRIZ matrix:[6] Stability, an engineering parameter to improve (number 13), versus form (12); the applicable inventive principles are 22, 1, 18 and 4. Stability (13) versus volume of moving object (7); some solution principles are 28, 10, 19 and 39. From these principles, the segmentation principle (1) inspires a new design: a structure evolving from one floating part into two separated floating parts which have a smaller structure and a better appearance.

Other oppositions were studied: Speed (9) versus shape (12): the matrix gives the following inventive principles: 35, 15, 18 and 34. Speed (9) versus energy spent by moving object (19): the inventive principles are 8, 15, 35 and 38. From these principles the following solutions were inspired: a counterweight to increase propulsion wheel inertia, holes in propulsion blades, an improved hydrodynamic shape, etc.

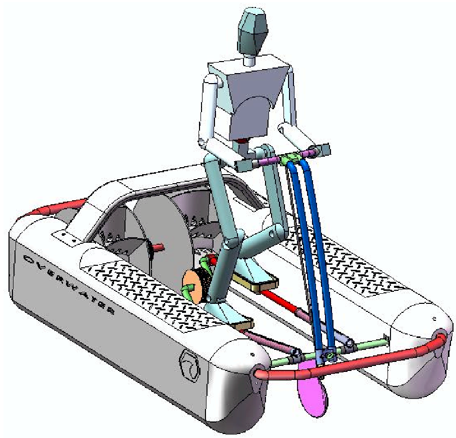

Figure 1. Individual small boat "Overwater"

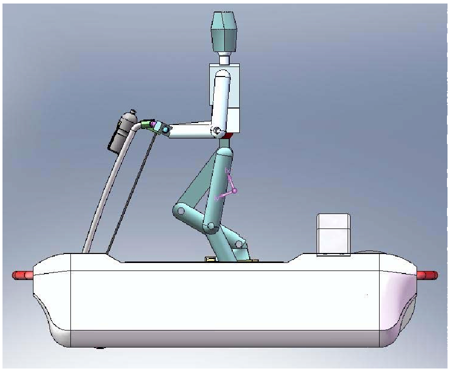

Figure 2. Lateral view of the individual small boat.

3.2. Survey

Students were surveyed about the development of the course at the end of the 2006-07 and 07-08 courses. They agreed in the way that theory and practical sessions were distributed. On the other hand, they thought that the number of tools presented was too large and that some should have been examined in more depth. Furthermore, some said that their workload was too heavy. These remarks had also been made in years prior to this experience.

4. CONCLUSIONS

Design tools are abundant in the literature. The tools used in this Product Engineering and Technical Systems I (EPISTI) course are some of the most frequently used by engineering designers. For this reason, it is of great importance that students become familiar with them.

Exploring a larger number of tools than in previous years implies dealing with them at a more superficial level. However, it has proved useful in strengthening student work. It is also true that student work lacks homogeneity, but in general it is of reasonable quality.

The student survey reveals that they find the course structure satisfactory, but consider the amount of work that they are expected to do too great.

In order to achieve homogeneity in the level of knowledge acquired by all [1] members of the work groups, future modifications are planned for the 2008-09 course. One consists in giving students a written examination to check their grasp of course material. This means that all students must know and understand all design tools described in class. Additionally, some tools will be explained but their used will not be practised.

Students must study and practise the use of several design methodologies and tools in engineering design courses. Perhaps the Bologna Process provides an opportunity to enhance the quality of engineering design studies in the Engineering School (ETSEIB) of the Technical University of Catalonia (UPC).

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