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INTEGRATED DESIGN OF AN ECONOMICAL VEHICLE THROUGHOUT THE MECHANICAL ENGINEERING CURRICULUM OF A POLYTECHNIC SCHOOL

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Abstract. *A multidisciplinary experience is presented involving the Mechanical Engineering and Industrial Management departments of a Polytechnic and an University. The scope is focused in teaching engineering, regarding the project, construction and development of a vehicle intended to participate in the Eco-Marathon race. A methodology is presented concerning the student's team composition, the selection of pre-projects, the tutorial accompaniment over several scientific areas and the replacement of curricular laboratory experiences by the project and development's equivalent work. The final aim is to get a better adjustment of the engineering students to the needs of the industrial sector.*

Keywords: *Mechanical Engineering Education, Pedagogy, Didactics.*

1. INTRODUCTION

The Portuguese industrial sector, though nowadays experiencing a thoroughly integration in the European Union's major market, and therefore expecting the results that will derive from an irreversible work division, is characterized by a dominant small and medium enterprise's sector, which has been challenging, with considerable versatility, the innovation's trends that are typical of today's economical activity. In recent works, those trends were reflected concerning the country as a whole (Martins, 1994), particularly its center region (Simões and Matos, 1997), and a sensible effort was made for human resources formation, centered in the polytechnic vector, monitored in a technical level by APET and FEANI, the european board of engineering accreditation. Being a polytechnic school, cooperating with a major university for curricular purposes, this last decade changes in students profiles prompted us with the need for fresh thinking on how engineering should be taught. Also, the different levels of ability revealed by the students when entering graduation, influencing their degrees of motivation, has been one main issue of concern that has lead to the promotion of a strong experimental component in curricula, from concepts to open-ended problems.

On the other hand, and from a outlet point of view, while it is undoubtedly true that specialists that have an in-depth knowledge of a specific area will always be needed, there is nevertheless an increasing demand for those who can integrate ideas from different areas. One has recognized in industry's wishes a strong demand for the workplaces of teamwork ability, cooperation and collaboration (Meyer-Dohm, 1990, Simões *et al*, 1999). Team work developed around initiatives like this one fulfills part of the need for exercising those capabilities, creating conditions for active learning habits and cooperative learning. The whole process of launching the challenge of actually building an economical vehicle to compete in the international Shell Eco-Marathon race, selecting groups and check the commitment at different stages previously defined in the process, intended to provide opportunities both to observe high quality thinking in others and allow feed-back of each element's own contribution (Gibbs, 1986). In order to keep an acceptable level of deliverable work and integrate the technical areas approached or touched in all the phases of project and development, a system of intermutability curricular lab work was designed to allow switching, depending on tutor's recognition of value for project work, such as Machine Elements, Fluid Mechanics, Electronics and Operations Management. Finally, there is an intention to reach the industry emphasis on required development of skills, qualities and attitudes, relevant not only to active learning throughout the life but also to individual initiative, readiness to accept responsibility, self-confidence and problem solving skills (Buonopane, 1997).

2. EXPERIMENTAL

The department decided to carry over this initiative by involving all it's internal sections, beginning with the specifications sheet and definition of constraints. The competition's principle is to cover six laps with three or four wheels vehicles from the competitor's own concept. The distance must be completed within a maximum elapsed time of 48 min, representing a minimum average speed of 25 km/h. Some other technical regulations include mandatory identification and position related to trade marks and names of sponsors and equipment fitted on the vehicle, the fuel tank and fuel system and control and. Competitors are classified according to their fuel consumption, the winner being the one that reaches the lowest fuel consumption.

2.1 Project launching

This consisted of several phases, in order to start student's motivation: bringing Oporto University's car to the Polytechnic school, realizing a seminar in which students could turn around the exposed car and place questions, and showing its behavior in real conditions (Fig. 1). A first set of constraints, whose grounds were explained to the students, were established, concerning the number of team's elements, it's composition in terms of curricular years, the maximum budget the department would consider and its full material commitment to support eligible teams until the final steps of the process, as long as teams would observe the defined and to define internal regulations.

Figure 1- Eco- marathon's vehicle publicizing tour.

2.2 Project development

One month later, the project constraints were communicated and a first set of requirements defined, so that first options would be taken. The internal regulation to allow candidature's admission concerned the presentation of a sustained proposal over the following issues:

Technics. Indication of motor type: 2 strokes or diesel for 1st-3rd year teams, 2 or 4 strokes 3rd-5th year teams (the reason was to keep it simple to first year teams, regarding their level of engines knowledge, and allowing future developments, in terms of injection for instance, for more curricularly advanced teams); choosing the frame type: tubular (welded) or shell; 3 or 4 wheels. Furthermore, a plan with dimensions both for the overall and the parts was to be furnished

Aesthetics and aerodynamics. A sketch or a drawing of the vehicle that would allow assessing the form and external dimensions as well as an evaluation of the drag.

Project management. Sponsors and marks to get in touch with, project planning and execution, all in recognizable due form, as taught in curricular Project I discipline.

Of the initial 8 teams formed, only 3 reached the above requirements presented one month later. During the meeting that then took place, the teams suggested that, in order to keep an acceptable level of work, curricular laboratory work should have the possibility of switch with correspondent eco-marathon's work. This suggestion was accepted after some internal discussion with department's professors, and a mechanism was established that gives the possibility, each semester, to make that switch, as long as tutor's recognition of value for project work and professor's recognition of adequacy consensus is reached. This system is in place for Structural Mechanics, Materials, Electric Machines, Fluid Mechanics, Instrumentation, Operations Management and Project I and II.

2.3 Project scheduling

The next step was to commonly elaborate a schedule, intended to assure the teams participation on the Paul Ricard French race. That schedule consisted of a presentation of external benchmarks regarding the vehicle's manufacture, the complete frame production, the engine integration and the wheels assembly and transmission. Depending on these items a final decision would be taken regarding the Paul Ricard's deadline inscription. The final steps were the vehicle's complete building and readiness for essays, and the date of the race itself.

3. PROJECT MANAGEMENT

Recognizing that it was a typical case of applying project management techniques, still the mission was somehow more difficult and more demanding than programming operations in manufacturing processes, as the action occurs in a organization with a school's characteristics: graduation schools assume, normally, an adhocracy configuration (Mintzberg, H., 1996), a democratic organizational model insuring good sociability between different areas specialists, a good propitious ambiance to research and innovation, but that places, occasionally, efficiency and efficacy difficulties. Schroeder (1993) assessment that "the planning and scheduling of projects is concerned with the unique, onetime production activity", stresses that we were confronted with the project and manufacture of a unitary product, focused towards a final goal- to participate in the Shell Eco Marathon's race.

The project management was previously designed and developed taking into account the following vectors:

3.1 Communication and motivation

Communication to the environment, scholar and entrepreneurial community, and the society in general, that Polytechnic's teams were participating in the event, enforced the schools notoriety and strongly motivate students to participate, assuming difficulties and risks and inducing entrepreneurial capacities and proactive attitudes, thus counterbalancing other less attractive activities of school life. Therefore, and since the beginning, a policy communication was defined in order to capture resources from school, raise funding and obtaining sponsorships and publicity, activities developed by the teams themselves with tutor's backup predicted in the organizational scheme.

The schools integration was promoted through a first approximation of future engineers to enterprises, putting their best abilities to work for personal marketing, interacting with the real world, dealing with adversities and difficulties of resources capture, always present when it comes to achieve initiatives.

3.2 Organizational model

The previously selected organizational model assumed a matricial structure, represented in Fig. 2, where a leader's existence is explicitly put to evidence in each team, a student elected by his peers, as well as a teacher designation to act as a tutor for each team. From Chase and Aquilano (1995), "a matricial organizational structure keeps some of the positive characteristics of the functional group, giving the project manager some input and control. (...) The project manager concurrences with other department's programmed works, as well as with other project managers, in order to achieve each work within each functional area. Here's an area which requires true capacities from a good project manager: the capacity of having the work done while keeping a good relation with the functional managers."

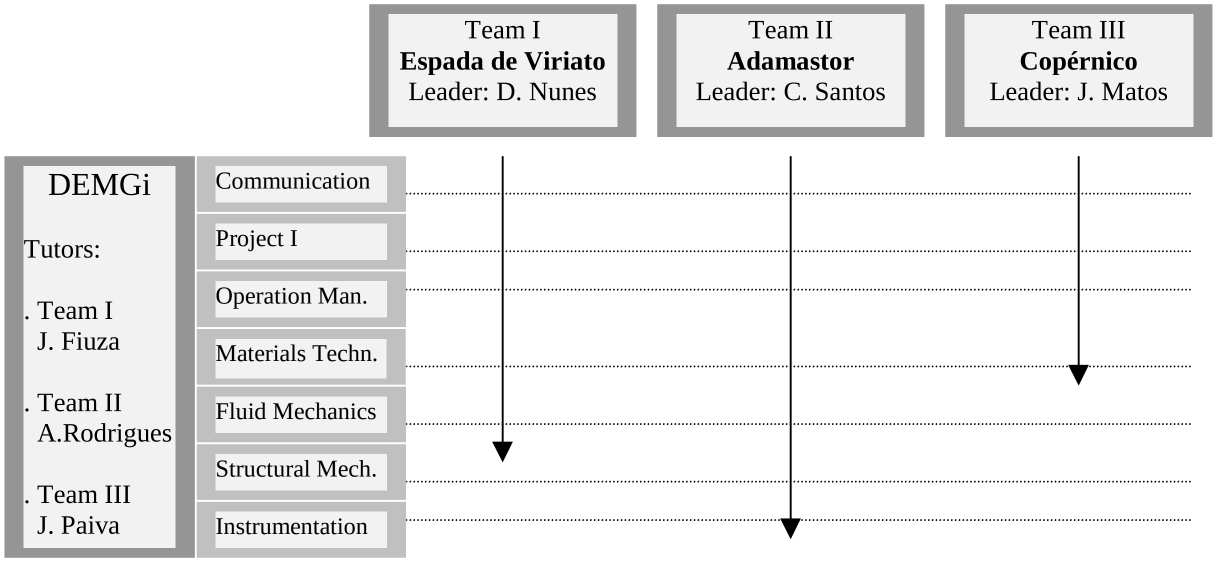

Figure 2- Organizational model.

This model was considered the best fit to the functional characteristics of a school and fulfils, once more, the primer task of giving future engineers professional skills in the organizational behavior field.

3.3 Planning, scheduling and manufacturing control

In planning, scheduling and manufacturing control, usual techniques from industrial engineering in project management were used, namely the Gantt graphics (Fig. 3), PERTs (Program Evaluation and Review Technique, Fig. 4) and control reports for projects progress assessment.

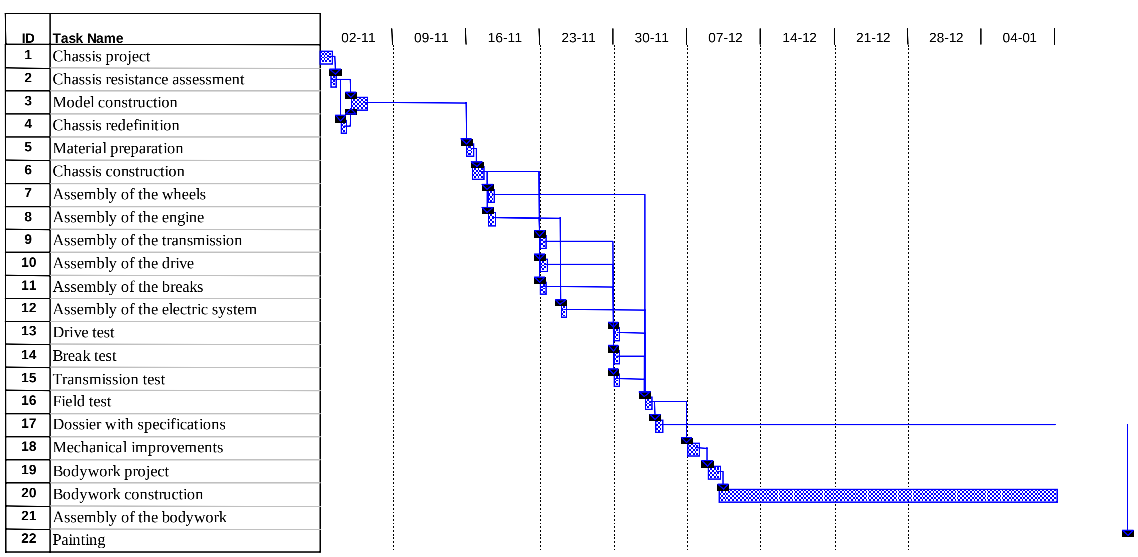

Figure 3- Gantt diagram applied to the vehicle project.

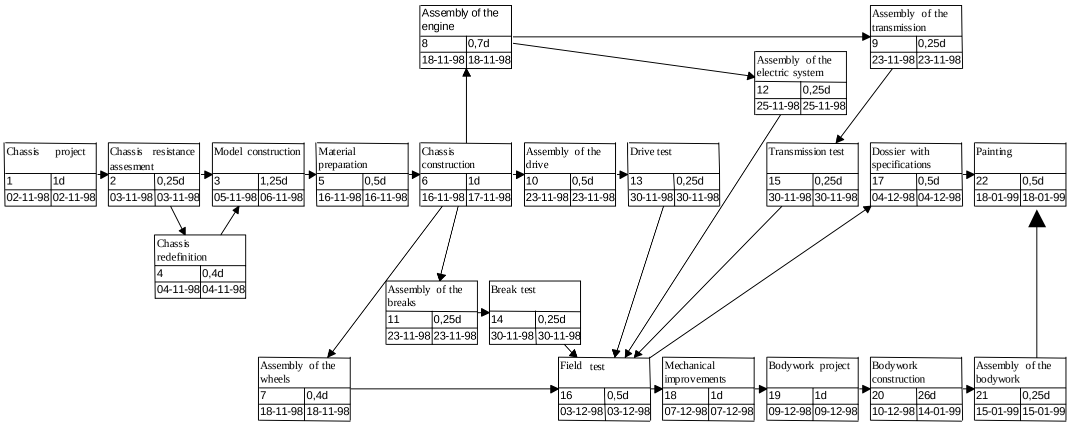

Figure 4- PERT diagram applied to the vehicle project.

4. INTEGRATION THROUGHOUT THE CURRICULUM

4.1 Project

The third year Project chair has a professional nature, oriented towards industrial management areas, as students are able, once finished those three years, to apply for a professional certificate, delivered by the Portuguese Association of Technical Engineers (APET) that will allow them to start working as professionals. Either wanting to keep studying, or returning, years later, to Polytechnics, the fifth year of the following cycle has a mechanical engineering Project, were students are introduced, more deeply, into conception of mechanical systems. Being the remaining two teams composed by first cycle students, third year Project I was the focus of integration project work into curricular scope.

Students were involved in planning and defining different activities, resources allocation and delays establishment, feeling the importance and implications of an adequate project management, especially in what concerns the importance of good successful work planning.

The action and task planning constituting the eco-marathon project were converging actions for rationalization and optimization of means and resources, so that they would be available in the right moment. Beyond PERTs, Gantts charts and Charging maps, there was a study on appropriate execution time management regarding conception/design, calculation, redefining conception, construction, assembly, tests and elaboration of a dossier with technical specification data.

4.2 Structural Mechanics

Project: conception and design. Vehicle dimensions, according to the race regulation dimensions definitions, and general form were defined, along with frame architecture basic resistant structure and different machine elements and a first wooden frame was built (Fig. 5), allowing dimensional corrections so that all the mechanisms and components would be checked for accommodation (number of wheels, engine, transmission), drag coefficient could be assessed and some ergonomic solutions validated (driver’s position and size).

Calculations and design re-conception. A sketch of the structure was made using a commercial design package (Fig. 6) and the aluminum structure designed according with Mechanics of Materials principles.

Figure 5-Wood frame prototype.

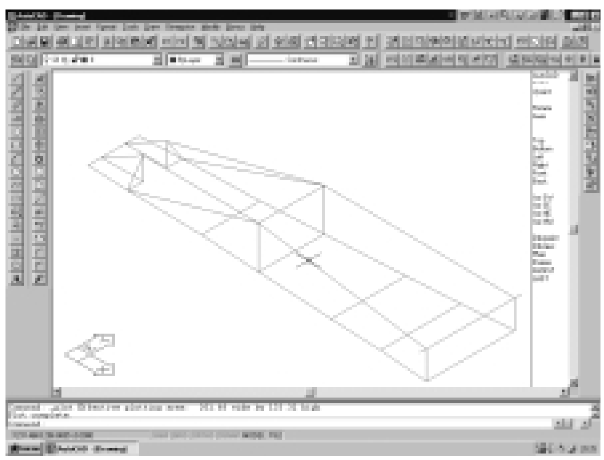

Figure 6-Frame prototype design.

With the help of a software package (Fig. 7), the mechanical loads were calculated, as well as the respective bending and torsional moments, shear and normal stresses for each beam of the structure; the structure deformation was calculated as well. Mechanical properties of the aluminum beams were determined using the Strength of Materials laboratory equipment, in order to obtain the stress strain diagram. As a result of this analysis changes to the structure and to the dimensions of the beams were successively applied, to get the final solution consisting of a tubular structure built in welded aluminum.

The use of this software package allowed, based in the loads originated by the engine, the driver, all other mechanical parts, and respecting security rules, determining all the relevant stresses applied to the frame (Fig. 7), giving students some significant feeling about this area.

Construction and assembly. One can point out all the work developed making contacts with several corporations, regarding parts acquisition, catalogue search, choosing and defining parts to use. Welding being used in frame's manufacture, knowledge concerning welding joints studied in Materials Technology was put in practice, using welding machinery, mechanical saw, lathes and milling machines of the Machine Tools laboratory.

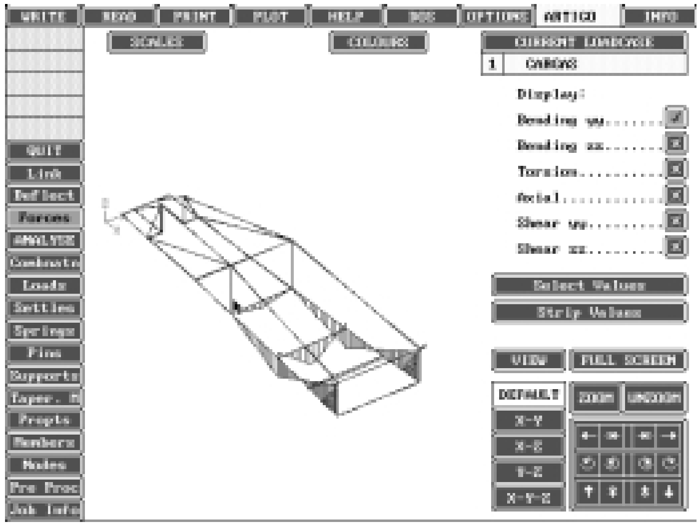

Figure 7-Frame structure forces determination.

4.3 Materials Technology

In Technology of New Materials two lab works were planned so that structural adhesive joints and composite materials would be applied in the car's cockpit/shell. The composite materials were analyzed as to their influence in the strength and weight. The results obtained, shall be presented to the student's peer through formal presentation and discussion.

4.4 Fluid Mechanics

In Fluid Mechanics classes, students have contact, mainly, with internal flows, which is believed to constitute the major part of practical approach during their future professional lives. In doing these projects they face typical external flow problems, like minimizing the drag force over the vehicle, which, beyond the aesthetics point of view, is one of the major constraints defining its shape. Students understand that they must care with the drag but also with the frontal area as well; and they find the real importance of the $C_D A_f$ product, and focus their attention on its minimization.

There are some other concepts that students are susceptible to grasp more deeply: the pressure drag and the friction drag. The vehicle's shape must avoid the rear separation zone, as the pressure drag has a sensible effect on the overall drag value; and students shall consider that minimizing global drag coefficient can be attained increasing the superficial area - and friction drag - of the vehicle, mainly in the trailing edge. This was an eminently empirical discussion with and among team members attending fluid mechanics classes. In the near future a scale model will be tested in the wind tunnel.

When students choose the engine for the vehicle, they must decide about displaced volume, torque, power, fuel consumption and efficiency. This promotes an active and deep learning of this concepts.

On the other hand they learn about carburetors and electronic fuel injection systems as alternative ways of obtaining the optimum air-fuel ratio for the engine.

In the near future it will be possible to test the engine and the adopted solutions in order to obtain its performance parameters.

5. RESULTS AND CONCLUSIONS

We believe that this kind of experience promotes active and deep learning of concepts; develops students personal skills and promotes interpersonal skills.

Knowledge application/active learning (Barnes, 1989):

1. choosing and using different sort of welding;
2. application of polymers;
3. distinction between stiffness and strength;
4. distinction between friction drag and pressure drag;
5. distinction between power and torque...

Capacities acquired/skills developed (Brown *et al*, 1983, Candy and Crebert, 1990)):

1. time management skills: dealing with deadlines, organizing tasks;
2. cooperation, collaboration, team work capacity;
3. communication skills: ability and improvement of communication with the real world;
4. leadership;
5. learning/practicing a foreign language...

The obtained results with this experience were extremely positive, so future initiatives will be promoted in order to involve students in this kind of extra curricular activities, which are an effective help in getting a better adjustment of the engineering students to the needs of the industrial sector.

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