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Cooperative project-based learning for machine design in the Industrial Engineering Program: Methodologies and experiences

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1. Introduction

In the industrial engineering program of University Jaume I in Castellón (Spain), students can take in the fifth year an optional one-year specialization in electromechanical engineering. This specialization was introduced to boost the industrial goods and machinery sector in the province of Castellón. The powerful ceramic sector in Castellón (that accounts for the 80% of the whole Spanish ceramic production) utilizes mainly imported machinery because of the lack of Spanish industrial companies devoted to this specific sector.

The authors of this paper teach four different courses belonging to this electromechanical specialization:

- Advanced Machine Design,
- Automatic Regulation,
- Electric Machines Control, and
- Design for Manufacturing and Assembly.

From the beginning, they have introduced machine project and design learning in the different courses considering a realistic, integrated and collaborative vision in such a way that each student has to participate in a specific machine design project considering all the mechanical, electrical and manufacturing aspects.

Within this project, the students are expected to develop the skill to design a real machine not only using the knowledge acquired in the different subjects about mechanical, electrical and regulation aspects, but also improving their cooperative capabilities.

The project also requires teaching coordination tasks between the teachers involved in order to define and supervise the work developed cooperatively by the students. Also, new methodologies have been introduced in each subject which not only improve the learning of that subject but can also be used in the rest, enhancing the cooperative approach of the project.

It is not easy to find in the bibliography many references about similar experiences in the Spanish universities including a complete description of the used methodology and the reached results. In fact, engineering teaching in most of the Spanish industrial engineering schools is traditionally divided in different independent and isolated courses that focus mainly in analysis aspects but lack the necessary synthesis or design facet. Consequently, the global design of a multi-disciplinary system has been habitually avoided.

In the international environ, there is a stronger tradition in this kind of learning activities, especially in the US, where many engineering programs devote one or two terms to a specific integrated project experience (capstone design experience). Many conference communications deal with the methodology and results of different teaching experiences based on mechanical or electromechanical system design projects (Marvel & Reffeor, 2002; Archibald, et al., 2002; Brackin & Gibson, 2002; Neal, et al., 2002; Giolma & Nickels, 2002; Williamson & Winzer, 2003; Mirman, 2005; Cambpell & Schmidt, 2005; Abdelmessih et al., 2005; Batill, 2002).

The interest in the preceding project-based learning activities is mainly imposed by the conditions or criteria derived from the ABET engineering and technological degrees accreditation system (http://www.abet.org). In this accreditation system, some general objectives (called a, b, c, …, k) are established, including, in addition to technical and scientific knowledge (criteria a and b), system design competencies (c), an ability to function on multi-disciplinary teams (d), an ability to communicate effectively (g), an ability to use modern engineering tools (k) and so on.

In this work, the machine design learning experience through the last ten years and the used procedure is shown. The application of novel educational methodologies and coordination tasks to a real machine design, construction and regulation project is also addressed.

During this time, different coordinated design projects have been proposed to the students, but some parts of this work focus on proposed project during year 2007 in order to explain in depth the different educational methodologies involved on the learning process.

2. Objectives

The academic goals of the project development are the following:

- Improve the practical education of the students with the realization of a real machine design work.
- Improve the students' workgroup abilities.
- Make the students responsible of their own learning, promoting in this way their autonomy.
- Improve the interdisciplinary coordination between different subjects of the Electromechanic intensification of the Industrial Engineering program.
- Teach the students the main phases of a machine design process.

To reach these goals, a practical engineering project is proposed.

3. Project Based Learning. Work organization

The students coursing the elecromechanical specialization must achieve the specific objectives of each of the four courses plus the objective of being able to successfully finish an interdisciplinary project working in groups.

3.1 Working groups definition

The working groups are formed by three students, with the goal of forming a group with enough working capabilities in order to develop the technical aspects of the project, and with the goal of promoting their cooperative abilities. Furthermore, the number of members fits the number of roles to be adopted by each member and the number of the partial reports to be delivered.

All the members of the group work with the objective of obtaining a viable design for the machine, and all of the members must do specific and different tasks on all the parts of the project.

At an organization level, through each of the design phases each of the members of the group assumes a role for the development of the different partial works to be delivered. Once each phase is finished, roles are rotated between the students, so that each student assumes in turn all the different roles. The three different roles and the main tasks connected to them are:

- Supervisor:
    - Organizes the group meetings and acts as a moderator.
    - Assigns tasks, schedules the work of the members.
    - Supervises the tasks and is the responsible of the technical quality.
    - Writes an act of each meeting.
- Document responsible:
    - Establishes the structure of the text and the contents of the documents resulting on the finalization of each of the assigned tasks.
    - Gathers all the documents to generate the final report, being responsible of the quality of the document.
- Spokesman:
    - Prepares the slides to make the oral presentation of the work.
    - Cooperates with the document responsible to make the presentation coherent with the document, being the responsible of the quality of the presentation.
    - Represents the entire group and must defeat all the technical developments of the work in front of the teachers and the rest of the students.

The accomplishment of the tasks connected to each role is taken into account for the evaluation of the students, as well as the general quality of the technical work.

3.2 Tasks schedule

As one of the objectives of this academic experience is to teach the students the main phases of a machine design process, from the very beginning these phases, as well as the main tasks in each one, are established clearly:

- Specification definition: This phase is carried out by the teachers who, considering the academic goals of their subjects, propose a specific machine to be designed and a list of required and/or desired specifications.
- Conceptual design: In this phase, the students have to identify the functional structure of the machine, search for solution principles for each of the functions and select the best of them.

- Preliminary design: For each of the modules found in the previous phase, the students design their fundamental variables, such as dimensions, electric power, etc…
- Detailed design: Calculation of every designed element, and selection of commercial components. Specification meeting is also checked in this phase.
- Final report: At the end of the course, a final report with all the content required in a technical project as the one carried out is written.
- Electrical prototype building: Parallel to the final report, a real prototype of the electrical and control part of the project is built and set up by the students in the university labs.

The three intermediate phases finish with a handed report and an oral presentation that are scheduled with duration of three, four and five weeks each. The final report and a short report of the experimental prototype results are delivered five weeks later (after the courses' exams have finished).

4. Case Study

In order to illustrate some of the different educational methodologies used, in the following section the project carried out in year 2007 is shown as an example. That year, the objective of the project was the design of a training static bicycle with an electrical recovery system. The students' proposals had to meet the following specifications:

- The system must include a regulation for a comfortable use by adults of different sizes (percentiles between 5 and 95).
- The force level required by the user for the pedalling must be tuneable, in order to be adapted to different preparation or training levels.
- The energy generated on the pedalling must be transformed into profitable electrical energy.
- The energetic efficiency of the system must be as high as possible.
- The machine will be designed for an average production of 2000 units per year during 5 years.
- The machine must be safe for the user and accomplish the European regulations on machine safety, so it can get the CE mark.
- It must be designed for the use in gymnasiums or at home.

5. Educational Methodologies

The project methodology used has had slight variations since its starting point in the academic year 98-99, regarding changes in the involved courses, working groups' definition, tasks schedule, assessment procedure and educational methodologies. Particularly, during the development of the different project phases, the teachers apply different educational methodologies and teach them in such a way that the students can apply them in the rest of the courses that form the specialization. The use of these methodologies in the different phases can be summarized as follows:

- In the conceptual design phase, the students have to recognize the different subsystems with the help of concept maps creator software. Later, different options for each subsystem are studied and proposed, in order to choose the best one that fits the requirements of the project. In this phase several methodologies have been used: a group investigation methodology, gathering information from a variety of sources, and a decision matrix methodology, which helps in the decision process.

- In the detailed design phase, the students use a simulation software to study the behaviour of the mechanical, electrical and regulation systems. With the simulation software the students are able to test the system in its whole operating range, which helps them to calculate the different mechanical and electrical components, detect design problems and try different control systems, always in order to obtain the most effective machine. Self-directed learning is encouraged in this phase.
- At last, the prototype building consists of the assembly of the electrical machine with the required power circuit, the signal electronics, and the microcontroller that is also programmed to control the machine in its whole operating range. This part involves some of the most complex tasks, and cooperative techniques methodologies (such as Aronson's Jigsaw technique) have been proposed so that every student in every group is able to study in depth the machine and set it into motion.

Next, these different methodologies are discussed in detail.

5.1 Concept Maps

One of the methodologies proposed to the students for the concept design phase is the use of concept maps using the CmapTools software. Concept maps are graphical tools for organizing and representing knowledge (Novak & Cañas, 2006). They were developed in 1972 in the frame of a research program to study the learning of children (Novak & Musonda, 1991). They include concepts, usually enclosed in circles or boxes of some type, and relationships between concepts indicated by a connecting line linking two concepts. Words on the line, referred to as linking words or linking phrases, specify the relationship between the two concepts. CmapTools is a free software developed by the Florida Institute for Human Machine Cognition (IHMC) to help construct concept maps. It allows creating, formatting and arranging concepts and linking words using a graphical interface.

Concept mapping is a powerful tool to achieve meaningful learning. In the context of the machine project presented in this paper, concept maps are useful to establish graphically the relationship between the functional blocks used in the machine. In this sense a concept map can be equivalent to a functional diagram. Each of the functions needed to be solved in the machine represents a concept and the linking words establish the connections among them, which can be physical connections, or transfers of raw material, energy or signal.

Figure 1 shows an example of a concept map generated by a group of students for the static bicycle project. Figure 2 shows a concept map for the structural function of the static bicycle.

5.2 Research Group

The research group methodology was introduced by (Slavin, 1980) in the environment of cooperative learning and it is based in the research of a group about a question that is of their interest to start the project. The students look for and organize the information and present it to the rest of implied groups. In this technique, the students do not have a detailed solution for the problem if they only use the information acquired in the normal lessons of

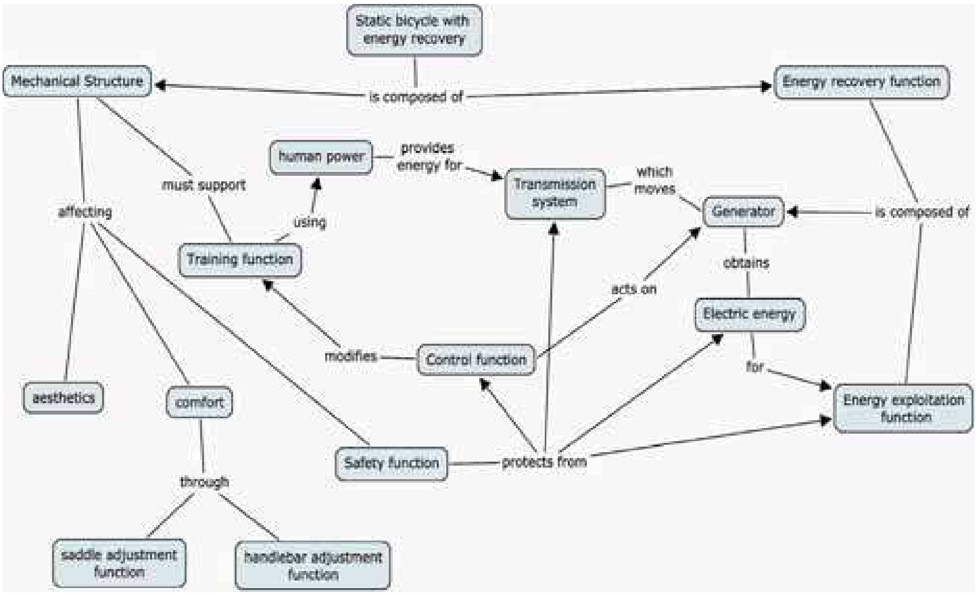


Fig. 1. Concept map of the static bicycle with electrical recovery

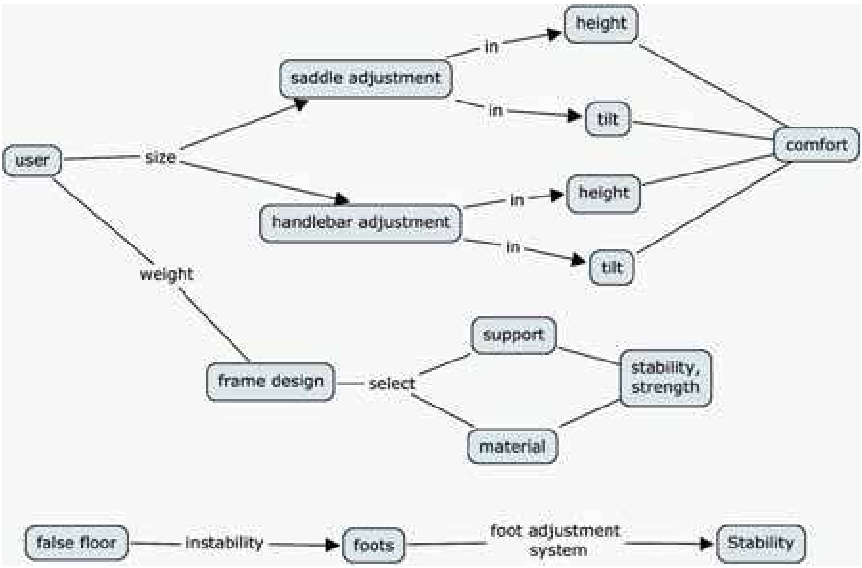


Fig. 2. Concept map for the structural function of the static bicycle.

the subjects of the Industrial Engineering program. For that reason, the students have to study a novel problem and have to look for different solutions for the given problem.

In the frame of the static bicycle project, the methodology of research groups has been introduced in order to help the group to choose the electric generator and the control system from all existing technologies. These technologies are mostly unknown to the students, as in previous courses they have mainly studied electrical machines as well as power drives and converters from a motor operation point of view, instead of a generator operation one.

The research group methodology is developed as follows:

1. The problem needed to be solved, transforming mechanical energy into electric energy and take profit of this, is introduced by the teacher.
2. Students and teacher discuss which aspects of the different solutions are important to choose one of them: speed range, energetic efficiency, electric machine power, simplicity of regulation, economic cost, etc.
3. Students gather information from a variety of sources (text books, other courses class notes, manufacturer datasheets, internet, etc.) in order to select the best option according to the previous aspects, and make some important decisions (i.e. store the generated energy with a battery or supply it to the electric grid).
4. Each group exposes their work to the rest of the students and the teacher. They show all the options considered and defend their choice. This way, other groups can learn from them, taking into account approaches they didn't and applying them in upcoming phases of the project.
5. The research work is evaluated. This evaluation considers mainly the range of the options studied as well as identification of advantages and disadvantages of each approach.

The different solutions that the students have found are combinations of the different motors (induction motor, synchronous generator, DC machine, brushless motor), power drivers (rectifier, inverter, chopper), control schemes (analogical, digital, with microcontroller-based logic) and systems to take profit of the generated electrical energy (battery storage or electrical grid direct connexion).

Once the different solutions have been found, the decision methodology explained in the next section was used to find the most reasonable solution, that result to be the use of a DC machine with a complete controlled rectifier controlled with a microcontroller and connected to the electrical grid.

5.3 Simultaneous selection of materials and manufacturing process using decision matrices and weight factor

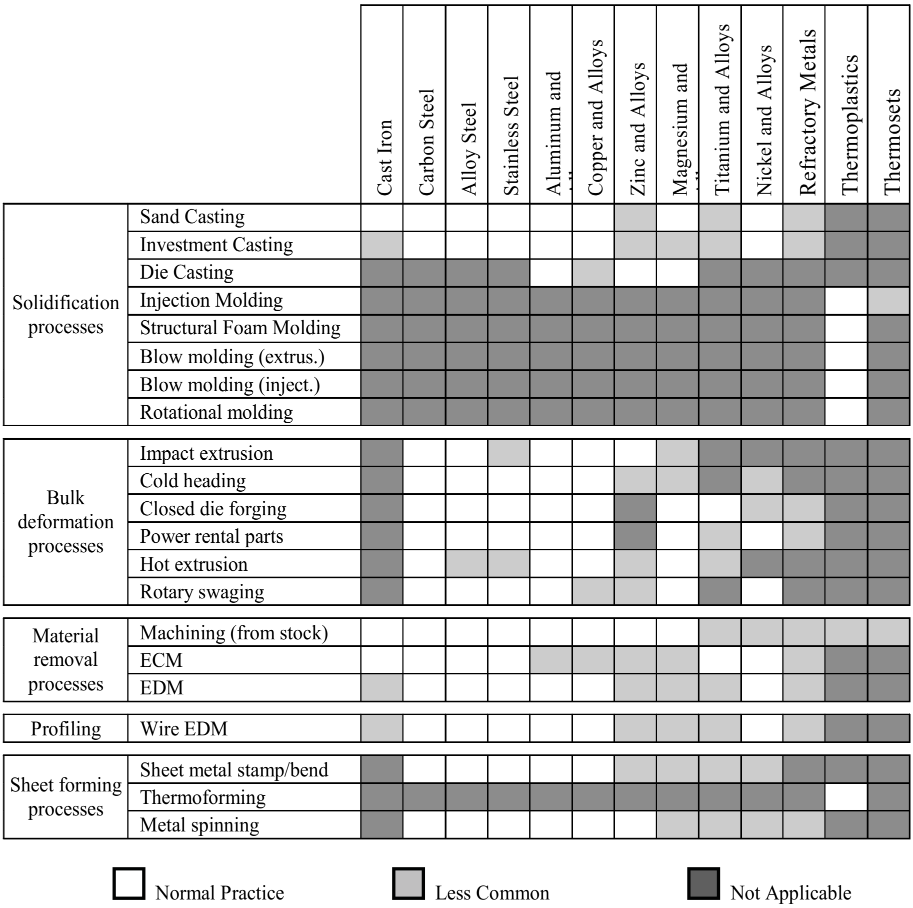
In the different design stages of a product, decisions regarding part material and geometries must be taken, being both of them closely related with the manufacturing process.

Additionally, requirements to be met by different product parts have been established during conceptual design. These requirements and restrictions will have an important effect on materials and manufacturing processes, such as mechanical resistance, elasticity, corrosion, temperature, cost, assembly suitability, production quantity and batch size, etc.

All this makes the selection process complex and long, if an optimal solution is to be achieved. Therefore, two methodologies/tools have been proposed to help and ease the selection process. They can be sequentially applied, once a pre-selection of possible materials has been done:

1. Use of process-material and process-geometry compatibility matrices (Boothroyd et al., 2002). These matrices allow the elimination of those manufacturing process that are not capable of producing the required part, as well as materials that are not compatible with some manufacturing process/geometries. Figure 3 shows a compatibility matrix for a

selected range of processes and materials types, and Table 1 shows the shape-generating capabilities of the same range of processes.



		Cast Iron	Carbon Steel	Alloy Steel	Stainless Steel	Aluminum and	Copper and Alloys	Zinc and Alloys	Magnesium and	Titanium and Alloys	Nickel and Alloys	Refractory Metals	Thermoplastics	Thermosets
Solidification processes	Sand Casting	□	□	□	□	□	□	▨	□	▨	□	▨	■	■
	Investment Casting	▨	□	□	□	□	□	▨	▨	▨	□	▨	■	■
	Die Casting	■	■	■	■	□	▨	□	□	■	■	■	■	■
	Injection Molding	■	■	■	■	■	■	■	■	■	■	■	□	▨
	Structural Foam Molding	■	■	■	■	■	■	■	■	■	■	■	□	■
	Blow molding (extrus.)	■	■	■	■	■	■	■	■	■	■	■	□	■
	Blow molding (inject.)	■	■	■	■	■	■	■	■	■	■	■	□	■
	Rotational molding	■	■	■	■	■	■	■	■	■	■	■	□	■
Bulk deformation processes	Impact extrusion	■	□	□	▨	□	□	□	▨	■	■	■	■	■
	Cold heading	■	□	□	□	□	□	▨	▨	■	▨	■	■	■
	Closed die forging	■	□	□	□	□	□	■	□	□	▨	▨	■	■
	Power rental parts	■	□	□	□	□	□	■	□	▨	□	▨	■	■
	Hot extrusion	■	□	▨	▨	□	□	▨	□	▨	■	■	■	■
	Rotary swaging	■	□	□	□	□	▨	▨	□	■	□	■	■	■
Material removal processes	Machining (from stock)	□	□	□	□	□	□	□	□	▨	▨	▨	▨	▨
	ECM	□	□	□	□	▨	▨	▨	▨	□	□	▨	■	■
	EDM	▨	□	□	□	□	□	▨	▨	▨	□	▨	■	■
Profiling	Wire EDM	▨	□	□	□	□	□	▨	▨	▨	□	▨	■	■
Sheet forming processes	Sheet metal stamp/bend	■	□	□	□	□	□	▨	▨	▨	▨	■	■	■
	Thermoforming	■	■	■	■	■	■	■	■	■	■	■	□	■
	Metal spinning	■	□	□	□	□	□	□	▨	▨	▨	▨	■	■

□ Normal Practice ▨ Less Common ■ Not Applicable

Fig. 3. Materials-Manufacturing processes compatibility matrix.

2. Use of weight factors for material final selection. This methodology is based on assigning to each material or property requirement a *weight factor* (α) according to its relative importance. These weights are multiplied by a *scale factor* (Β), obtained comparing the property value for a specific material with the maximum or minimum value (depending on the case). Finally, a *comparison index* (γ) is calculated by the addition of weight factor and scale factor multiplication for each material, and selecting as the optimal material the one with the best index.

The scale factor can be calculated as:

$$\text{Scale factor} = \text{B} = \frac{\text{Numerical value of property} \times 100}{\text{Maximum numerical value of property}} \tag{1}$$

In case of properties to be minimized, such as cost, weight, etc., the scale factor can be expressed as follows:

$$\text{Scale factor} = \text{B} = \frac{\text{Minimum numerical value of property} \times 100}{\text{Numerical value of property}} \tag{2}$$

And the comparison factors as:

$$\gamma = \sum_{i=1}^{n} B_i \alpha_i \tag{3}$$

Figure 4 shows an application example of material selection by using the factor weight methodology for the structural frame (chassis) of the static bicycle.

Manufacturing process		*Depress*	*UniWall*	*UniSect*	*AxisRot*	*RegXSec*	*CaptCav*	*Enclosed*	*NoDrafi*	*PConsol*	*Alignmt*	*IntFast*
Solidification processes	Sand casting	Y Y	Y	Y	Y	Y	Y	N	N	4	3	1
	Investment casting	Y Y	Y	Y	Y	Y	Y	N	N	5	5	2
	Die casting	Y Y^a	Y	Y	Y	Y	N	N	N	4	5	3
	Injection molding	Y Y^a	Y	Y	Y	Y	N^b	N	N	5	5	5
	Structural foam	Y Y^a	Y	Y	Y	Y	N	N	N	4	4	3
	Blow molding (extrus.)	Y Y^a	P	N	Y	Y	P	Y	N	3	4	3
	Blow molding (inject.)	Y Y^a	P	N	Y	Y	P	N	N	3	4	3
	Rotational molding	Y Y^a	P	N	Y	Y	N	P	N	2	2	1
Bulk deformation processes	Impact extrusion	Y N	Y	N	Y	Y	N	N	Y	3	3	1
	Cold heading	Y N	Y	N	Y	Y	N	N	Y	3	3	1
	Closed die forging	Y Y^a	Y	Y	Y	Y	N	N	N	3	2	1
	Power rental parts	Y N	Y	Y	Y	Y	N	N	Y	3	3	1
	Hot extrusion	Y^d N	Y	P	Y	Y	N	N	Y	2	2	3
	Rotary swaging	N^c N	N	N	P	N^c	N	N	N	1	1	1
Material removal processes	Machining (from stock)	Y Y	Y	Y	Y	Y	Y	N	Y	2	3	2
	ECM	Y Y^c	Y	Y	Y	Y	N	N	N	3	4	1
	EDM	Y Y^c	Y	Y	Y	Y	N	N	N	3	4	1
Profile generating processes	Wire EDM	Y^d N	Y	Y	Y	Y	N	N	Y	2	2	3
Sheet forming processes	Sheet metal stamp/bend	Y Y	P	Y	Y	Y	N	N	N	4	3	4
	Thermoforming	Y Y^a	P	N	Y	Y	N	N	N	3	3	3
	Metal spinning	N N	P	N	P	N	Y	N	N	1	1	1

a: Possible at higher cost.
b: Shallow undercuts are possible without significant cost penalty.
c: Possible with more specialized mach me and tooling.
d: Only continuous, open-ended possible.
Y: Process is capable of producing parts with this characteristic.
N: Process is not capable of producing parts with this characteristic.
P: Parts produced with this process must have Ibis characteristic.
An underlined entry indicates that parts using this process are easier to form with this characteristic.
The last three columns refer to DFA (Design For Assembly) guidelines and are rates on a scale of 1 to 5, with 5 assigned to processes most capable of incorporating the respective guideline.

Depress:	Depression, ability to form recesses or grooves in the surfaces of parts.
UniWall:	Uniform wall thickness.
UniSect:	Uniform cross section, any cross sections normal to a part axis are identical.
AxisRot:	Axis of rotation, parts whose shape can be generated by rotation about a single axis.
RegXSec:	Rectangular cross section, cross sections normal to the part axis contain rectangular pattern.
CaptCav:	Captured cavities, ability to form cavities with reentrant surfaces.
Enclosed:	Parts that are hollow and completely enclosed.
NoDraft:	Draft-free surfaces, capability of obtaining constant cross sections in direction tooling.
PConsol:	Part consolidation, ability to incorporate several functions into a single piece, eliminating others.
Alignmt:	Alignment features, the ease of incorporating in the part location features aiding to assembly.
IntFast:	Integral fastener, ability to incorporate features which generally involve separate fasteners.

Table 1. Shape generating capabilities of manufacturing processes.

Obviously, both described methodologies can be applied in the other subjects involved in the project. For instance, to pre-select the possible control systems for a driver and select the optimal one; or the most appropriate power transfer system subject to a specific set of requirements and constraints, as it was done after the possibilities on generators, power drivers and energy management were explored with the help of the research group technique.

Weight factor for each requirement	
Requirement	**Weight Factor (α)**
Manufacturing cost	35%
For medium production quantity	30%
Relative cost	20%
Density	15%

Value of property material vs requirement				
Material	**Manufact. Cost**	**For medium prod. quant.**	**Relative Cost**	**Density (kg/m^3)**
Low-Carbon Steel	Very Good	Very Good	1	7,850
Aluminum	Good	Good	4	2,700
Copper	Very Good	Very Good	9	8,920
Brass	Very Good	Very Good	20	8,800
Titanium	Fair	Fair	28	4,507

Scale factor (B) material vs requirement				
Material	**Manufact. Cost**	**For medium prod. quant.**	**Relative Cost**	**Density (kg/m^3)**
Low-Carbon Steel	100	100	100.00	34.39
Aluminum	75	75	25.00	100.00
Copper	100	100	11.11	30.27
Brass	100	100	5.00	30.68
Titanium	50	50	3.57	59.91

Comparison factor	
Material	**Comparison Factor (γ)**
Low-Carbon Steel	*90.159*
Aluminum	*68.750*
Copper	*71.762*
Brass	*70.602*
Titanium	*42.200*

Fig. 4. Material selection for the structural frame of the static bicycle

5.4 Simulation-based self-learning.

One of the goals of the project is the improvement of the self-learning capability of the students. In order to do this, the students are required to develop their own system with the help of a simulation software.

During the preliminary design of the machine, the students are required to use a simulation software in order to autonomously understand in depth the operation of each of the elements of the electromechanic system. To solve this phase, students work mainly by themselves, as the simulation software allows them to do so without any damage. In this context, the teacher's tasks are the following:

- Help the students in the self-planning of their work. The main tasks to be performed, as well as their sequence, have to be determined.
- Give all needed information about the use of the simulation program.
- Offer individual assistance, out of the normal class context, to solve problems and progress in their simulation work.

In the specific case of the static bicycle project, the students have been required to simulate the system shown in figure 5.

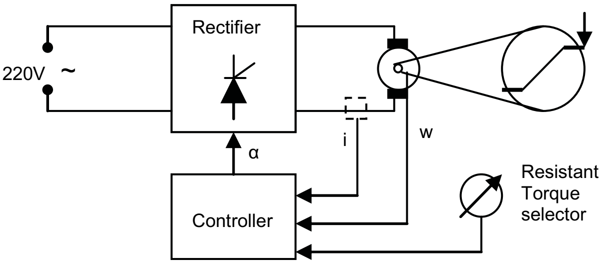


Fig. 5. Electrical system to be simulated

In this system, the torque applied to the pedals by the user of the static bicycle is transmitted to the shaft of the DC machine. The resistant torque that finds the user in the machine, which to meet the project specifications must be adjustable, is directly proportional to the generated current. As the current supplied to the electric grid goes through a controlled rectifier, the current magnitude in the DC machine will be a function of the firing angle (α) and a function of the angular speed of the shaft (w). In order to assure that it is supplied to the grid the current equivalent to the selected resistant torque, a controller is introduced in the system making use of the measurements of current, angular speed and resistant torque selector, and changing the firing angle in the rectifier to assure a proper operation.

The simulation software that has been used is SIMULINK® from MATLAB®. The students have implemented and simulated the complete electromechanical system in the following order:

1. The operation of the DC machine has been simulated in the four quadrants in order to improve knowledge of the operation of a DC motor as a generator and electromagnetic brake
2. A complete controlled thyristor-based rectifier has been setup and tested with different loads in order to improve the knowledge about the relationship between the different variables that interact in the driver (firing angle, extinction angle, inductance, input and output current waves, input and output voltage levels, etc.).
3. The DC machine and the rectifier have been assembled and the operation of the DC machine has been analyzed as a function of the parameters of the rectifier (firing angle and smoothing inductance, mainly) and the mechanical system (mainly, the inertia of the mechanical system, that is something to be calculated).
4. A complex control system with nonlinear elements has been added to the system in order to achieve a correct tracking of the current demand, i.e., the resistant torque indicated by the user at each moment when doing a normal training.
5. Finally, It has been analyzed the effect of the parameters of the control system, the electrical DC machine, the smoothing inductance and the inertia over the efficiency of the complete electromechanic system, so that the students are able to search for the most effective solution to the problem.

The simulation software has been found to be a very useful tool in the self-learning process, as it helps to analyze separately the different subproblems, and the relations between them. It helps also in order to let the students use a trial and error approach without any risk.

In figure 6 it is shown one of the block diagrams developed by the students during the preliminary design.

5.5 Aaronson’s Jigsaw

Once the students have studied in depth the different problems that must be taken into account in the operation of the electrical system during the preliminary design, in the detailed design phase they have to develop a real system, choosing all the electrical and electronic components and programming the control algorithm that regulates the machine operation.

To do so, the students have been required to use the Aaronson Jigsaw (Aaronson, 1978) in order to achieve the goal on time, and, mainly, to improve their cooperative abilities. The Aaronson Jigsaw is a method that involves students' moving from a study group to an expert group in which they all work to solve the same subproblem, with more information than the original group. Once the experts in each expert group have solved the subproblem, agreeing on what has been important in the solution of the problem, they return to their study groups and take turns in those groups teaching what they know about the subproblem they solved in the experts group. Since their study group peers have just come from other expert groups on related subproblems, by the end of the session each group has a complete overview of the solution of the complete problem. They should be ready to assembly the different subproblems that solve the complete problem with some extra effort.

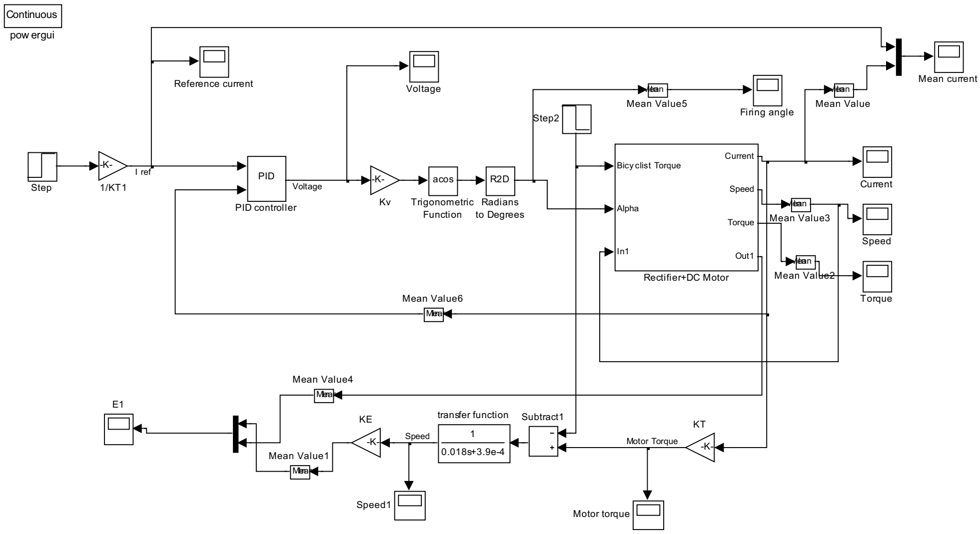


Fig. 6. Block diagram of the electromechanical simulated model.

In figure 7 the electrical and electronic circuit that has been developed is shown, where the different parts can be enumerated as follow:

a. Power electronic circuit. It has a direct current generator whose shaft is mechanically connected to bicycle, an inductance L to soften the current, a current transducer to measure the generated current, and a complete controlled thyristor-based rectifier that is connected to the electric grid to produce the adequate voltage signal in the generator with the use of the signals of the trigger circuit.

b. DSP: is the microcontroller that has to be programmed, and it is used to measure the different signals of the system and to control the operation of the controller rectifier. The signals to be measured are:

- shaft speed;
- generated current, using the current transducer;
- the reference of the current to generate, using an analogic input; and
- the digital signal generated in the zero crossing detector, using an special digital
- input able to generate an interrupt on the DSP.

The signals to be generated on the DSP are four digital outputs that control the trigger circuit.

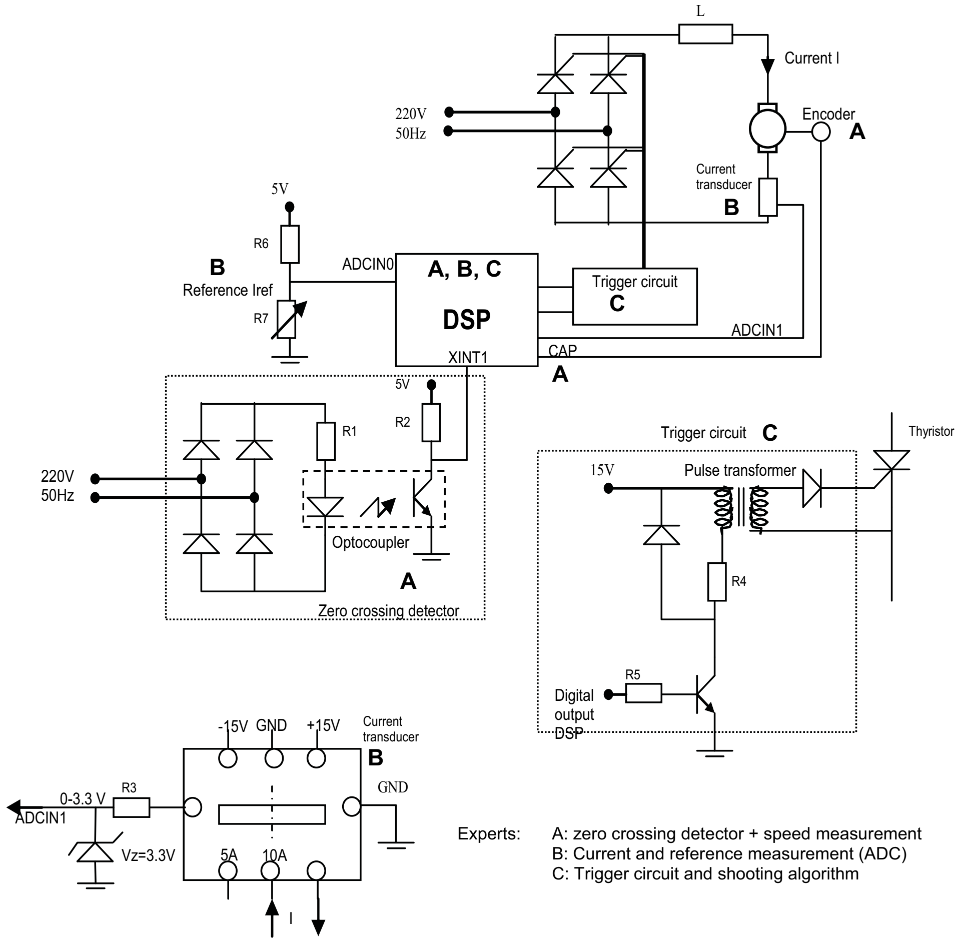
c. Zero crossing detector: generates a pulse signal when the sinus crosses the zero value. That pulse must be used to interrupt the DSP in order to update the control action and achieve the system requirements

d. Current measurement: generates a signal proportional to the current in the generator (I) that is connected to the analogic-to-digital converter.

e. Trigger circuit: this circuit commutates the thyristors using the digital signals generated by the DSP. The instant in which the thyristors are commuted depends on the zero crossing instant, the current reference, and on the measured current on the generator.

f. Speed measurement: the generator has an encoder connected to its shaft, whose signal is used by the capture unit of the DSP to measure the speed.

g. Reference measurement: a potentiometer is used to generate an analogic signal proportional to the demanded torque on the shaft. That signal must be connected to the analogic-to-digital converter of the DSP.



Experts: A: zero crossing detector + speed measurement
B: Current and reference measurement (ADC)
C: Trigger circuit and shooting algorithm

Fig. 7. Complete electrical and control system developed.

As it has been shown, this phase of the project design involves several complex tasks in order to achieve a suitable operation of the machine, including calculations in order to select several electronic components and generation of several pieces of programming code.

However, the problem can be divided into a few interrelated easier subproblems, which makes it suitable for an Aaronson Jigsaw methodology. Consequently, three phases have been defined:

1. Problem analysis. Each workgroup has a meeting to study the problem and to decide which member will participate in each of the expert groups. The expert groups are defined by the teachers, and have been defined so the amount of work and difficulty is equilibrated, being the groups and the subproblems to solve, the following:
   - Expert group A: Zero crossing detector (c), speed measurement (f);
   - Expert group B: Current measurement (d), reference measurement (g);
   - Expert group C: Trigger circuit (e).

Once the problem is studied by the workgroup, the three experts must take into account where is the connexion between the solution of their subproblem and the solution of his partners.

2. Expert groups. Then, the expert groups meet in order to solve the assigned subproblem and show the solution to the teachers for its evaluation.
3. Project finalization. With the results obtained from the expert groups, the original workgroups meet again and then, with the help of the three members (that have participated in the three different expert groups) try to solve the complete complex problem.

The final solution consists on gathering all the generated code and connecting the different electronic parts of the circuit. Finally, each group has to program the controller and tune it experimentally in order to experiment with the complete system and prepare the final document with the final conclusions of the machine design project.

6. Results

6.1 Projects, reports and oral presentations

Table 1 shows a list with the different machine-design projects carried out in different years, indicating the number of groups for each year. Figure 8 shows the results of the students' designs for several years.

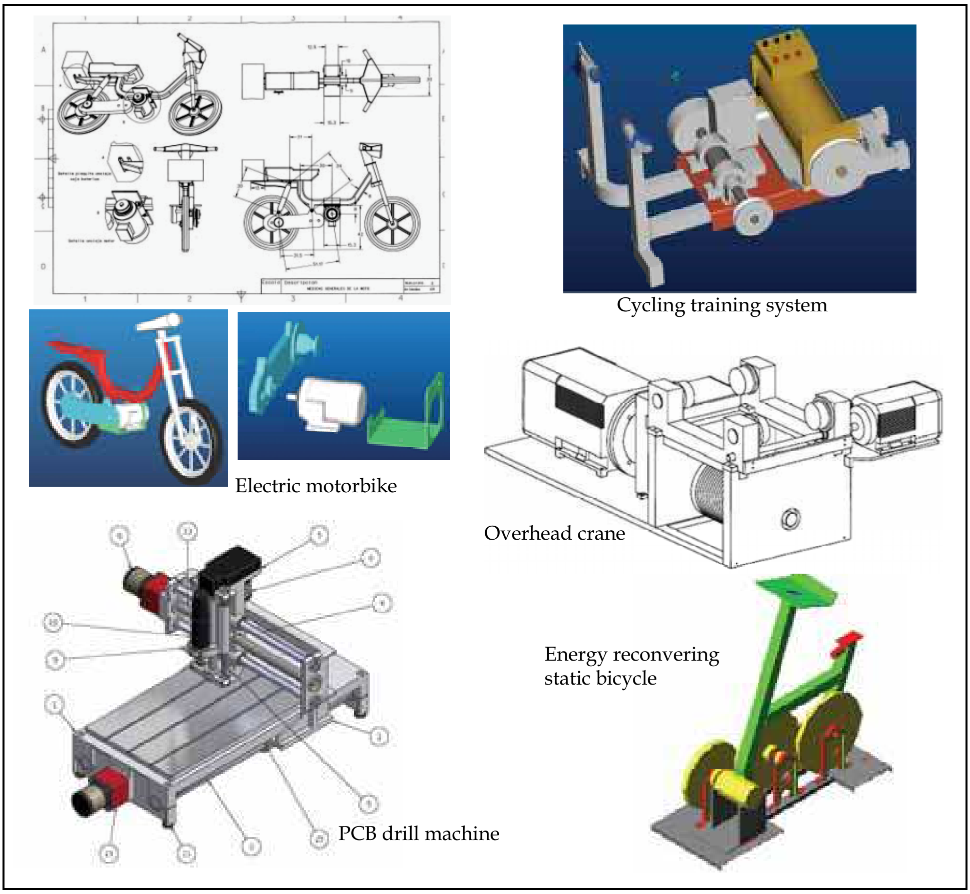
Generally speaking, the quality level of the projects developed by the students was acceptable from the point of view of the conceptual and preliminary design. However, in many cases, the detailed design was not completed or could be improved in some aspects.

Regarding the quality of the reports, the general impression was variable. Some projects were very well presented with excellent documents and maps and very good oral presentations. But, in other cases, the quality of the documents was poor, especially in the case of the detailed design maps with some lacks in the graphical information and contour maps. In the last years, the professors have encouraged the students about the importance of this aspect.

For the oral presentations, PowerPoint was required. Although the time limit was 15 minutes, students tended to take usually much more time. This shows a general lack of preparation for the presentations. Students' attitude during the presentation was, sometimes, timid and fearful, what denotes that this ability should be improved through the whole degree.

Year	**Number of groups**	**Project**
98-99	1	Car elevator
99-00	3	Overhead crane
00-01	3	Electric motorbike
01-02	3	Cycling training system
02-03	4	Cycling training system
03-04	2	Two axis sun tracker
04-05	3	PCB drill machine
05-06	2	Electrical bike
06-07	4	Energy recovering static bicycle
07-08	3	Fatigue test machine for springs

Table 2. Machine design projects


Cycling training system

Electric motorbike

Overhead crane

Energy reconvering static bicycle

PCB drill machine

Fig. 8. Projects designed by the students

6.2 Education methodologies improvements

The different educational methodologies presented have in general proved to be useful tools in the development of the project.

In the concept design phase, concept maps help the students form a precise idea of the different functional blocks that need to be designed in order to build the whole machine. Later, research groups and decision matrices respectively allow them to explore the different solutions to a specific functional unit and weight them in order to choose the best suited one.

The simulation software has helped to gain a deeper knowledge of every component of the machine, as well as making easier the calculations needed to choose and dimension the different machine components in the detailed design phase. It has been also a convenient way to encourage self-learning.

Lastly, the students have improved their cooperative abilities.

In figure 8 and 9, the mechanical and electrical design of one of the groups are shown, where it can be appreciated the level of detail that the students have achieved.

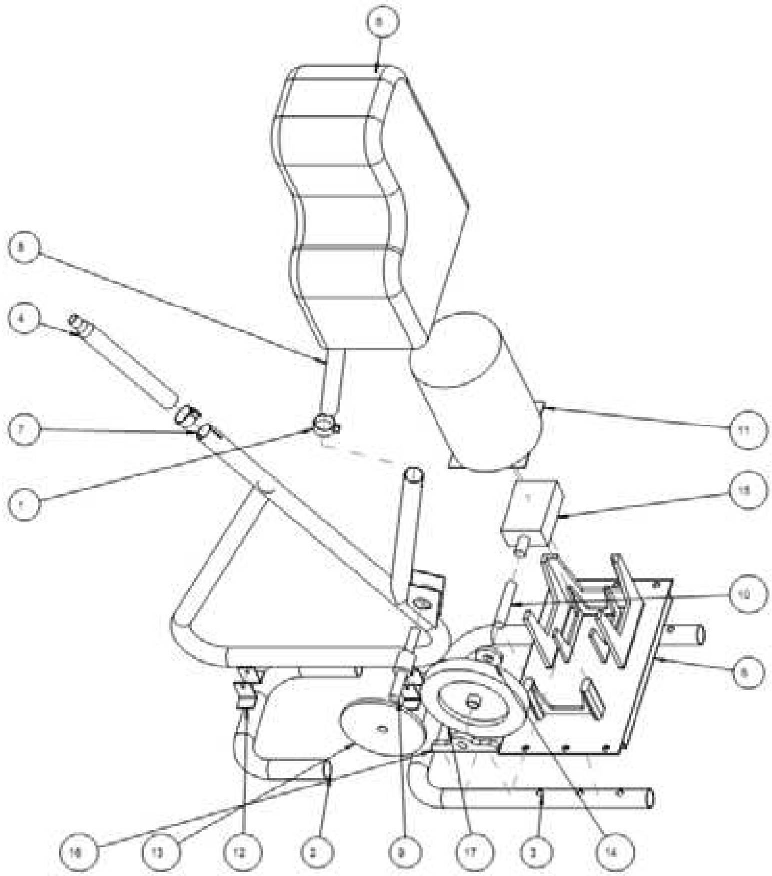


Fig. 9. Mechanical Design

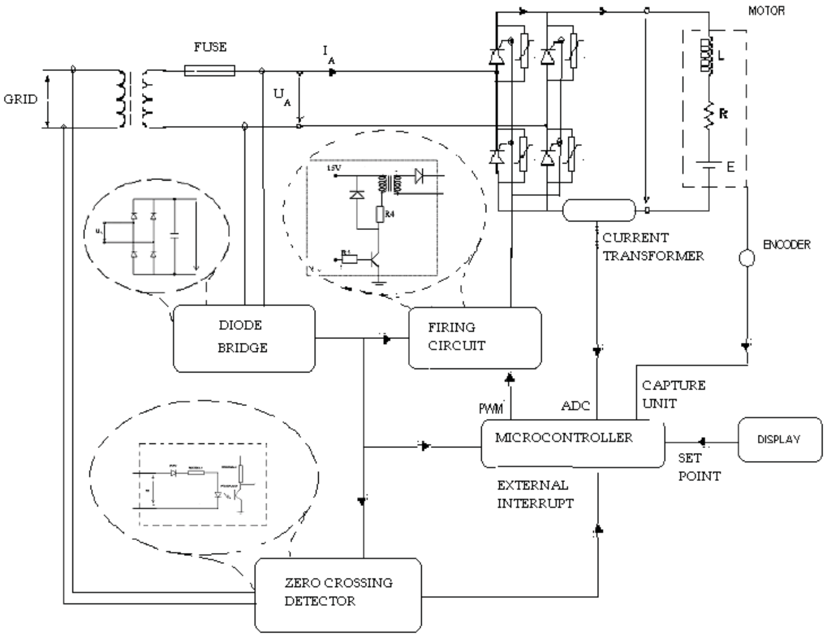


Fig. 10. Final Electrical design.

6.3 Prototype construction

Prototype construction was carried out for the first time, in the year 00-01. The project was an electric motorbike or, with more preciseness, the conversion of a traditional low power motorbike into an electric one. The prototype could not be completely constructed although the students developed the speed control and tested it with the selected electric motor.

In the following years, one of the main objectives was the construction of a prototype with the implication of the students. The general idea was that, taking into account the conceptual and preliminary designs made by the students, the professors would define a prototype design that would be constructed by the lab staff. According to this procedure, the cycling training system and the sun tracker prototypes, shown in figure 3, were built. In the next years, the professors tried to implicate the students more deeply in the manufacturing tasks, so they could improve their practical ability and help the professors in this time consuming activity. Each group was responsible for designing, selecting and acquiring the parts and building a subsystem of the prototype. However, the lack of collaboration between the different groups and the absence of a project leader made this task very complex and unsuccessful in most of the times.

In order to overcome those difficulties, two changes have been carried out in the last two years:

- The prototype construction has been restricted to the electrical and control implementation part of the machine, avoiding the heaviest time consuming manufacturing tasks.

– The Aaronson's Jigsaw technique has been introduced, improving the implication of the students in the prototype construction.

In the two years in which these changes have been introduced, the prototypes have been developed to a satisfactory level.

Figures 10, 11 and 12 respectively show the prototypes for the cycling training system, the sun trucker and the electrical part of the energy recovering static bicycle.

Fig. 11. Cycling training system prototype

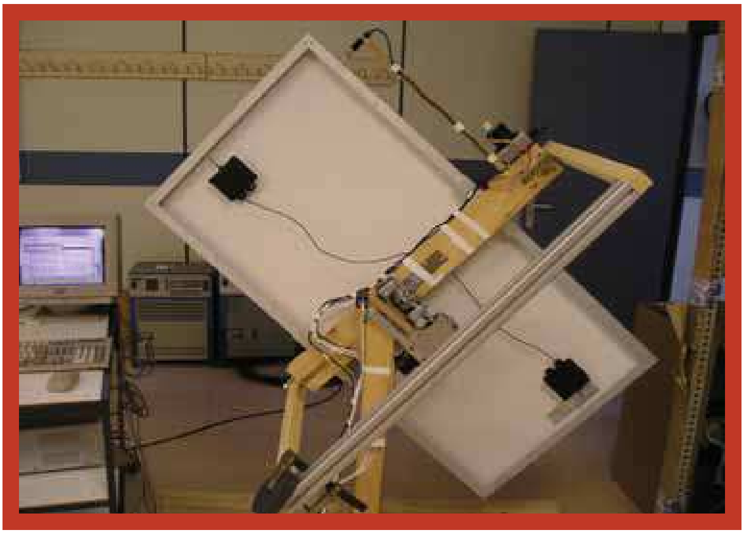


Fig. 12. Two axis sun tracker prototype

Fig. 13. Energy recovering static bicycle prototype

7. Conclusions

A machine design project is a complex and multidisciplinary activity. The experience acquired by the authors of this paper during the last ten years indicates that, in the environment of the industrial engineering degree, this kind of synthesis activity improves the training process of the students, mainly because they have to integrate the knowledge of different courses.

The development of the project has been supported with the use of different pedagogical methodologies in each of the phases of the project. The different methodologies that have been explained in depth in the environment of the machine design project are: concept maps, research group, simultaneous selection of materials and manufacturing processes using decision matrices and weight factor, simulation-software based self-learning, and jigsaw technique. With the use of the new methodologies, the students improve their cooperative abilities, their self-learning capabilities, and understand in depth each of the parts that compose the machine, that were unknown for them before starting the project.

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The widespread deployment and use of Information Technologies (IT) has paved the way for change in many fields of our societies. The Internet, mobile computing, social networks and many other advances in human communications have become essential to promote and boost education, technology and industry. On the education side, the new challenges related with the integration of IT technologies into all aspects of learning require revising the traditional educational paradigms that have prevailed for the last centuries. Additionally, the globalization of education and student mobility requirements are favoring a fluid interchange of tools, methodologies and evaluation strategies, which promote innovation at an accelerated pace. Curricular revisions are also taking place to achieved a more specialized education that is able to responds to the society's requirements in terms of professional training. In this process, guaranteeing quality has also become a critical issue. On the industrial and technological side, the focus on ecological developments is essential to achieve a sustainable degree of prosperity, and all efforts to promote greener societies are welcome. In this book we gather knowledge and experiences of different authors on all these topics, hoping to offer the reader a wider view of the revolution taking place within and without our educational centers. In summary, we believe that this book makes an important contribution to the fields of education and technology in these times of great change, offering a mean for experts in the different areas to share valuable experiences and points of view that we hope are enriching to the reader. Enjoy the book!

How to reference

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