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A Learning Through Play Approach to the Development and Assessment of General Competences in Electrical Engineering Based on a Student Competition*

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Student competitions are commonly used as part of engineering education curricula. This paper describes 'Race with the Wind', an international student competition to design and build wind generators, and presents an analysis of how the competition contributes to the acquisition of general competences within the Electrical Engineering curriculum at the Universidad Politecnica de Madrid.

Keywords: competences; learning through play; student competition

1. Introduction

Student competitions are commonly used in engineering education as a learning-through-play tool to acquire certain specific skills that are more or less associated with the curriculum [1–5]. In addition, and perhaps primarily, they are an excellent tool for developing a program's general competences, as [2, 5]. The meaning of the term 'general competence', used along this text, is similar to the terms educational objectives, skills, achievement [6] or outcome [7].

This paper describes 'Race with the Wind', an international student competition for the design and building of wind generators. The learning objectives are especially focused on the general competences of the Electrical Engineering curriculum at the Universidad Politecnica de Madrid (UPM), which are listed in Section 2. Since the general competences are similar in other engineering programs, the competition can be easily adapted to them.

The competition is described in Section 3, so that an interested reader can glean the general ideas and details involved in a successful competition. Along with the description, Section 3 includes an analysis of how the competition contributes to the aforementioned general competences. Section 4 compiles the results of the experience and describes our efforts for the future development of the competition in combination with a mini-project [8], focused on the adaptation of its technical aspects to reinforce some specific skills of the Electrical Engineering curriculum, and coordinated with the teaching methodology in the UPM Electrical Engineering Department [9].

2. Learning objectives

The competition is intended to contribute to the development and assessment of the General Competences (GC) in the framework of the Electrical Engineering curriculum at the Universidad Politecnica de Madrid, namely:

- GC1. To know and apply basic science and technology knowledge to engineering practice.
- GC2. To design, develop, implement, manage and improve products, systems and processes in different areas, using the appropriate analytical, computational or experimental techniques.
- GC3. To apply the acquired knowledge to identify, formulate and solve problems in broad contexts, working in multidisciplinary teams.
- GC4. To understand the impact of engineering on the environment, the sustainable development of society and the importance of working in a professional and responsible manner.
- GC5. To be able to communicate information, ideas, problems and solutions to both specialist and non-specialist audiences [10].
- GC6. To have developed the learning skills to undertake further studies with a high degree of autonomy [10].
- GC7. To include ICT and engineering technologies and tools in professional activity.
- GC8. To use written and spoken English.
- GC9. Organization and planning of projects and teams. Teamwork and leadership skills.
- GC10. Creativity.

3. The competition 'race with the wind'

This section describes the development and metho-

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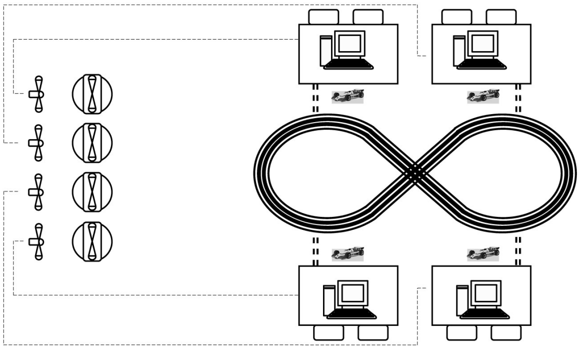

Fig. 1. Diagram of the competition layout.

dology employed in the international contest 'Race with the Wind', along with an analysis of how the competition contributes to the general competences. The contribution of the different parts or elements of the competition to each general competence is marked in the text by its identifier (GCi, for the ith general competence).

The event was organized by the European students association BEST [11], and by the Electrical Engineering Department at the UPM. The contest took place in Madrid during the first week of October 2009 at the UPM's facilities. There were 31 engineering students from 15 different European universities, and English was the official language used by the participants, the organization and the tutors. As stated above, the results of this experience have set the foundation for planning a new practical learning activity in the field of electrical generation with renewable energies, which will be included in the academic program of the Electrical Engineering curriculum at the UPM.

3.1 Description and scope of the competition

All the participants were distributed in seven groups with four students each, taking into account the academic curriculum of every student in order to maintain the desired multidisciplinary character of each team (GC3).

The first goal for the different teams was to design and build a small wind generator from scratch (GC2). Only some minimum characteristics and requirements were fixed by the organization team (GC6), who also provided the specific materials and equipment.

Once the wind generators were built, the second goal was proposed. The teams had to demonstrate the performance of their prototypes, in terms of the quality and the amount of the electrical energy generated, in a contest. Figure 1 shows a diagram of the facility where the contest was held, and which allowed for four different wind generators to compete simultaneously (a general view is also shown in Fig. 4). The wind incident on each competing wind generator was produced by means of four fans placed in front of each one. The electrical energy generated by each prototype was used to supply the current to a four-lane 'Scalextric' race car track. Obviously, the four tracks had identical racing cars.

Two elimination rounds, with four teams, were held in order to determine the two fastest cars in each round. The winning team was the one whose car completed the most laps in a given period of time, always fed by the energy supplied by its own wind generator. Table 1, shows some facts of the competition.

Although the most popular and coveted award was the Race Winner, some other prizes were awarded in several categories:

- Industrial design (GC10). Awarded to the best wind generator prototype, considering the compromise between appearance, originality and functionality.
- Aerodynamic design (GC1 and GC2). Awarded to the most aerodynamic blade design.
- Design of the electrical generation group (GC1 and GC2). Awarded to the wind generator prototype with the most efficient electric generator control system.

3.2 Classification of the competition

In addition to the above sketch of the competition, and before giving a more detailed description, it is interesting to show a more systematic approach to its characteristics. According to Verhoeff's classification [12], this competition is:

- Extracurricular.
- Fun-oriented, within a realistic context.
- Educationally oriented.
- Participatory, including teacher participation.
- Organized by students, for teams.
- International competition against others.
- Skill-oriented, with language dependence.
- Multiple-day event, with limited rewards.
- Flexible format, with delayed feedback.
- Multi-round tournament, with various competitor knowledge and skill levels.

Table 1. Competition facts

Participants	32
Teams / Students per team	8/4
Countries of origin	15 (Austria, Croatia, Czech Republic, France, Greece, Hungary, Italy, Latvia, Poland, Romania, Russia, Serbia, Spain, Turkey, and Ukraine)
Number of rounds	2

- Aimed at everyone, with little specialized training.
- Includes non-competitive elements, with official rules and a supervisory body.
- Limited to school topics, multi-disciplinary and sponsored.

From the above list, one can identify the contribution to most of the competences presented in section 2, particularly those identified as GC3, GC8, GC9 and GC10.

3.3 Competition schedule

The competition was held over the course of a five-day workweek, as shown in the schedule in Table 2.

As Table 2 shows, the participants' activity was complemented with academic lectures and seminars. There was also a preliminary contest in the middle of the week. These activities reduced the time available for the design, construction and performance tests to around 24 hours. In addition, it must be pointed out that the scope of this competition was completely unknown by the participants at the beginning of the week.

These particular characteristics are specifically addressed to force the participants to develop the following abilities: coordination and cooperation between team members (GC8 and GC9) so as to allot tasks and assume responsibilities; careful planning of the available time (GC6); and acquisition of a high degree of self-reliance in applying the knowledge to the development of a certain activity (GC1 and GC6).

The schedule was intended to allow all of the teams to finish the competition, despite any difficulties they might have had during the execution of the different activities. It must be pointed that this last objective was fully achieved since all the teams built a wind generator that was able to work properly during the final contest.

The following describes the content of the activities presented in Table 2, arranged chronologically:

- Lecture 1. First part: 'Race with the Wind'. This part was dedicated to present the planning, the contents, and the general participation rules for the competition, as well as the logistics. The dimensional limits, the materials and equipment available, as well as the final evaluation criteria, were defined.
- Lecture 1. Second part: 'Wind Power: Towards a global and sustainable access to energy'. This part was an introduction to the subject of wind generators, including the state of the art and the importance of the use of sustainable generation resources in electrical systems. This activity contributed to raise the students' awareness on the importance of the role that Engineering has in sustainable development (GC4).
- Seminar 1: 'Building a micro wind generator'. This seminar addressed the general aspects that should be considered when designing and constructing micro wind generators. The basic characteristics and behavior of the blades, the tower, the electrical generation group and the yaw system were detailed. Also, the technical characteristics of different commercial small wind generators were presented, to show some of the available solutions that might help the students when deciding on their own design (GC2).
- Seminar 2: 'Constructing a micro wind generator structure for this competition: an example'. The aim of the seminar was to convey the necessary practical knowledge concerning the aerodynamic and structural components of the micro wind generator. The theoretical basis of dimensional calculations was presented, and some tips on assembling small mechanical and structural components were given. Details of the nacelle and tower assemblies, the structural basis, the hub, the yaw mechanism and the blades were given. This facilitated the subsequent activity and also contributed to broadening the students' practical knowledge, for potential use in other engineering fields (GC6).

Table 2. Competition schedule

	Monday	Tuesday	Wednesday	Thursday	Friday
9:00–10:00	Lecture 1	Working session		Working session	Working session
10:00–11:00	Lecture 1 Seminar 1	Working session	Working session	Working session	Working session
11:30–12:30	Seminar 2	Seminar 3	Working session	Working session	Final contest
12:30–13:00	Formation of teams	Working session	Working session	Working session	Final contest
14:00–15:00	Working session	Working session	Working session	Working session	
15:00-16:00	Working session	Working session	Working session	Working session	
16:30–17:30	Working session	Working session	First contest	Working session	
17:30–18:30	Working session	Working session	First contest	Working session	

- Team structure: The criteria used to form the teams were the following:
  - Multidisciplinarity (GC3 and GC9) of the academic curricula of the members, such that each team includes a specialist in electricity, in mechanics and in electronics.
  - Internationality (GC8) of the different team members, to enhance each team's cultural background.
- Seminar 3: 'Electrical energy management: from the wind generator to the racing car'. This seminar detailed the characteristics of the electric and electronic components available for the students to build the electric generation group of the wind generator. The following elements were described: electric generator, racing car electric motor, components of an electronic kit (to build a DC/DC converter to adapt the voltage level of the wind generator to that of the racing car), and the control board of the electronic converter. Also, some possible algorithms for regulating the drive were explained. The knowledge acquired from this seminar aided the student in the design of the electric group (GC1), a task involving a high level of self-reliance (GC10), despite the fact that the same materials were available to all the teams.
- Lecture 2: 'Presentation of an industrial group'. A tower manufacturing company explained some technological aspects related to the construction, installation and maintenance of these metallic structures for high-power wind generators. As in Lecture 1, this activity contributed to training the students in the technological aspects of wind generators. Since the lecture was given by a company, they placed special emphasis on the technological and economic viability of each solution, always from a realistic point of view (GC4).
- First contest. In the middle of the week, a preliminary contest was held, with the aim of giving the participants the opportunity to gauge the progress of their work. This activity was very useful for the competition, since many mistakes could be corrected in time to prepare the prototypes for the final contest. This preliminary contest was held in the same facility as the final contest (see Fig. 1). After this test, the students had to collaborate closely with each other in order to solve the problems detected (GC3) and to make decisions accordingly.
- Final contest. This activity constituted the competition itself. The eight teams had to demonstrate, in two eliminatory rounds, with four prototypes fighting at the same time, which was the fastest car, supplied by the best wind generator design. Before the beginning of each round, one student from each team had to make a short public presentation introducing the team participants and the main characteristics of their prototype. Thus, the final activity contributed to developing the participants' ability to make a public presentation to a technically diverse audience (GC5).

3.4 Infrastructure

Each team had a work station consisting of a workbench with four chairs (Fig. 2, left). Each station was separated from the others by screens. It was used by the students in the design, calculation and programming tasks. There was a common workbench available to all the participants (Fig. 2, center). It was equipped with machining tools, such as drills, electric saws, sanders, etc. Adjacent to the common workbench, there was a wind generator test facility with a fan and a short segment of racing track, enough to test and adjust the various components of the wind generators being constructed (Fig. 2, right).

Finally, the contest facility was erected, as described in Section 3.1. Figure 3 shows a picture of the facility, where fans, power supplies, the race car track, structures for attaching the wind generators, flow regulation systems, protective fences, etc., can be seen. The fans had a flow capacity of 7000 m^3/h, enough to provide the wind generator placed in front with a 10 m/s wind speed. Furthermore, the fans were equipped with an air flow regulation system that affected the four prototypes in the same way. The wind generators were mounted on rotating platforms so that they could all be turned together in order to create oscillations in the wind direction. These last two mechanisms were designed to test the effectiveness of the wind generators' regulation and yaw systems.

3.5 Equipment

Each team had a laptop computer with engineering software tools and Internet access to search for information (GC7). In addition, the teams were supplied with different equipment and materials for the development and construction of each wind generator component, as detailed below:

- Wind turbine. A turbine hub and some material for the blades (PVC pipes, PVC sheets, attachments, etc.) were provided (Fig. 4, left). With this equipment, and within 40 cm limits for diameter/height wind rotor dimensions, each team had to decide on the construction characteristics of the wind rotor (vertical, horizontal, material, number of blades, etc.), the pitch angle mechanism, attachment to hub, etc.
- Tower and yaw system. The structural material

Fig. 2. Team workbench (left), common workbench (center) and wind generator test facility (right).

Fig. 3. General view (left) and a detail (right) of the facility during the final contest.

for the tower (PVC pipes), the bearings and the attachment elements to fix the nacelle to the tower and to control its orientation, were provided (Fig. 4, center).

- Regulated electrical generation group. The following equipment was provided (Fig. 4, right): MAXON 32/20W DC generator, electronics kit for building a DC converter consisting of NPN 2N3055 transistors, coil with a Ferroxcube P12/22 core, capacitors, resistors, diodes and adjustment potentiometers, and an 'Arduino Board Duemilanove ATmega168' computer interface board to control the converter. The purpose of this equipment was to obtain the maximum electric power from the wind generator under any wind conditions.
- Load element. This consisted of a Scalextric car with a 'SCX RX42' DC motor and a control potentiometer (handle). Both elements can be seen in the right part of Fig. 3, which was taken during the final contest. Each team had to make the necessary adjustments in order to conform their prototypes to the competition.

4. Results of the experiment

The first 'Race with the Wind' experiment was deemed successful, since most of the objectives were achieved. Next, an analysis on the accomplishment of these objectives is presented based on several criteria.

4.1 Construction of prototypes and accomplishment of deadlines

The competition objectives involving the work to be done and the deadlines set by the organization were fully met as intended. The students were able to complete the proposed tasks within the time given, and to solve the problems that arose during the development of the prototypes. Although they had to deal with a very tight schedule, in the end, every participating team was able to build a wind generator prototype that was able to produce enough electrical power to supply the racing car during the final contest. This confirms the viability of the activity proposed and the effectiveness of learning through play.

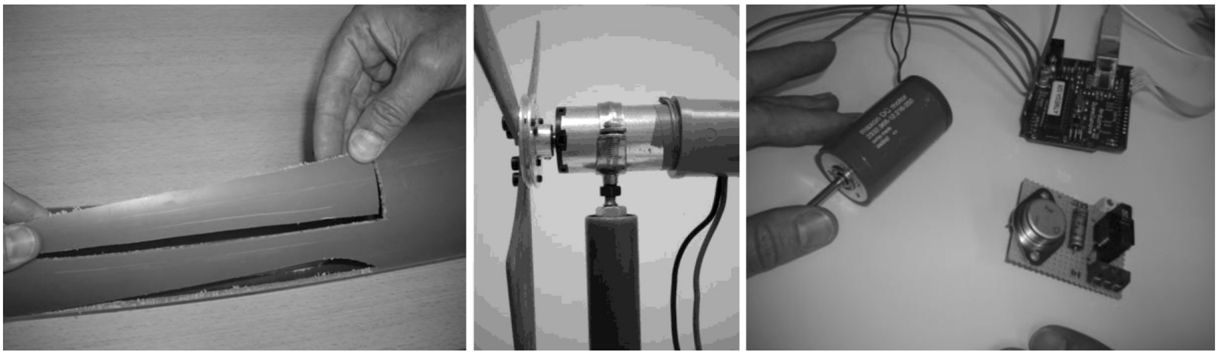

Fig. 4. Material for the blades (left), tower and yaw system (center), and parts for the regulated electrical generation group (right).

Although every team chose a horizontal shaft solution for the wind generator, they relied on different design configurations (number of blades, aerodynamic shape, yaw vane, etc.), thus showcasing their creativity (GC10).

4.2 The final contest

The contest was very exciting because there were very few critical malfunctions and almost every team had a chance to win. After the two classifying rounds, the four teams that had developed the 'faster' system in the race faced off in the final round. The final round featured two main competitors fighting head to head until the last turn, resulting in a thrilling event for both the participants and the spectators (see Fig. 3, right).

The pictures in Fig. 5 show the four award-winning wind generators:

- Most efficient prototype. This was the team that won the final contest, so it was the one achieving the best integration between design and control (GC1).
- Industrial design, based on the equilibrium between aesthetics, originality and functionality (GC10).
- Aerodynamic design, based on the rigor and care taken in the design and manufacture of the blades (GC1 and GC2).
- Design of the electrical generation group, awarded to the team whose prototype had the best regulation system (GC1 and GC2).

Fig. 5. Different wind generator prototypes built by the participating teams.

4.3 Feedback from the participants

Overall, the students reported a high degree of satisfaction in the surveys conducted at the end of the competition. For example, to the question 'Do you think you improved your technical skills?' 87% of participants answered Yes. And, to the question 'Do you think you improved your non-technical skills?' 95.7% of participants answered Yes.

When the organization team conducted its own satisfaction survey to its staff, which consisted mainly of student volunteers from BEST-Madrid, the result was similar to that of the participants.

4.4 Future developments

This competition has laid the foundation for the future progress of this learning activity towards a longer term project integrated as part of the Electrical Engineering program, which will include the design of an electrical generator. The competition gave us a chance to test the remaining tasks involved in the future long-term activity. This initial competition revealed the following:

- Using PVC was the easiest and most intuitive way to build the blades and does not require a detailed knowledge of aerodynamics.
- The yaw system, as well as the constructed tower segment and the way they are attached, can be the same, regardless of the machine used to generate electricity.

The objective of the project is to build a three-phase controllable windmill, using permanent magnets as the excitation system. The competition format used provides an appealing way for both students and professors to test and evaluate the designs, and also gives added motivation to the students while making it easy for them to learn about renewable energies. With regard to the European Higher Education Area, this activity will help to adapt to new educational plans in which teamwork will play a prominent role in assessing student learning.

5. Conclusions

The main result of the inaugural 'Race with the Wind' was that the participating students, as well as the organizational personnel, had a chance to incorporate an enriching experience into their training as future engineers and professionals. Not only did they have to broaden their knowledge of the technological fields involved in the experiment, but also, and more significantly, they had to work directly in the development of the competences included in the teaching objectives of this competition, as outlined in the previous sections.

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