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Assessment of Professional Competencies Promoted by SAE Formula Project: The UPMRacing Case*

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Promoting professional competencies is becoming an issue of interest and major concern in university environments. The assessment of individual students has usually been based on their knowledge and skills in solving problems on paper in an environment where time is scarce and information is restricted to the data given in the written instructions. However, the human resource managers of the major companies rate basic professional competencies very highly in the graduates that they take on, putting less importance on the level of technical knowledge possessed at the time of they are being taken on. In 1982 engineers from Ford, Chrysler and General Motors in the United States, being aware of how newly graduated engineers were adapted to automotive companies, designed a competition for universities throughout the world: Formula SAE. This competition involved conceiving, designing, manufacturing and competing with a formula-type vehicle. In 2003 the University Institute for Automobile Research (UPM—INSIA), was set up as the first Spanish Formula SAE competition team, called UPMRacing. The aim of this paper is the assessment of the professional competencies promoted by the Formula SAE project in individual students participating in the UPMRacing team. The compeTEA questionnaire© has been selected to assess competencies in the context of the UPMRacing team. This questionnaire has been applied to the team members in two milestones: when they start their participation (initial stage), and after they compete. Results conclude that this learning activity increases the professional competencies in a significant way, mainly in case of the students with the lowest level of professional competencies in the initial stage. Additionally, the main deficiencies identified in the participating students were the acquisition of organisational and planning competencies.

Keywords: professional competencies; Formula SAE; UPMRacing; assessment; psychometric test

1. Introduction

In the knowledge society of our time, the profile of a good engineer has to be based on the capacity and will to learn, in the solid knowledge of the basic sciences and in the good knowledge of some technology area, besides the general human values. Moreover, the engineer has to be prepared for permanent learning and also has to have communication skills and team work. The technical competences are not enough in the actual world [1, 2]. Human resource managers of companies rate basic personal skills in the graduates higher than the level of technical knowledge [3, 4].

Thus, for years the enhancement of theoretical-practical knowledge is only one of the educational goals sought. For instance Bowen et al. [5] and Chadha and Nicholls [6] raise the issue of assessing skills promotion in different universities in the United Kingdom. Aware of all this, those who designed the great European university paradigm (Bologna Declaration [7]) recognise the importance of introducing activities into the training programmes that help to promote abilities and skills in students.

Since the advent of ABET Engineering Criteria 2000 (EC2000), accredited engineering programs have been required to help students develop specific competencies. ABET is recognized as the worldwide leader in assuring quality and stimulating innovation in applied science, computing, engineering, and engineering technology education [8].

The School of Industrial Engineers of Madrid (ETSII) is an academic reference for national and international engineering education in Spain. Founded in 1845, it provides formal qualifications in Industrial Engineering, Chemical Engineering, and, according to Bologna Declaration [7], Degrees in Industrial Technology Engineering and Chemistry Engineering. ETSII, as part of the Technical University of Madrid, is one of the main engineers school in leading industrial engineering experience, demand for admissions, innovation and international expansion.

The prominent position that the School has held for several decades was renewed in 2010 with the ABET accreditation, conceded by the federation of 30 major associations in the field of engineering in United States. ETSII has become in the first engineers public school in Spain in being recognized with the ABET certificate and one of the first in Europe.

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Years before university education became fully aware of the importance of promoting personal and professional skills, companies in different sectors recognised the gap existing between university and business, and proposed activities to reduce this gap. For instance, in 1982 engineers from Ford, Chrysler and General Motors, grouped together in the SAE (Society of Automotive Engineers, United States), designed a competition for universities throughout the world, which involved conceiving, designing, manufacturing and competing with a small Formula-style race car. This competition was called the Formula SAE.

A group of ETSII professors, belonging to the University Institute for Automobile Research (UPM—INSIA), created in 2003 the first Spanish Formula SAE competition team, called UPMRacing. It was their answer to the need for introducing changes into the teaching activities consisting of promoting the skills most demanded by a sector as competitive and complex as the automotive sector. Formula SAE was selected as the most interesting and complete educational activity focused on the improvement of personal and professional skills in automotive engineering students [9].

As more engineering programs are now incorporating global competency into engineering it becomes more important to have choices of assessment methods for those outcomes.

The aim of this paper is the assessment of the professional competencies promoted by the Formula SAE project in individual students participating in the UPMRacing team. The assessment of students learning within team-based subjects is a challenging task, due to the high levels of complexity inherent in the socially team-based learning environment. The compeTEA psychometric test has been selected to assess competencies in the context of the UPMRacing team [10].

2. Methodology

2.1 Formula SAE competition

The concept behind Formula SAE is that a fictional manufacturing company has contracted a student design team to develop a small formula-style race car. The prototype race car is to be evaluated for its potential as a production item. Each student team designs, builds and tests a prototype based on a series of rules, whose purpose is both ensuring on-track safety and promoting clever problem solving.

The prototype race car is judged in a number of different events. Competition score is divided into two types: static and dynamic events. Besides, there are a group of preliminary tests that do not score, but need to be overcome. Table 1 shows a brief description of these events.

For assuring uniform and equal opportunities in the competition, Formula SAE sets strict standards to the design and manufacture of the different vehicle parts in addition to severe safety standards. Each university must present a project as if it involved a company that manufactured 1000 vehicles per year for an amateur public competing at weekends, and with a cost of less than $25 000.

2.2 UPMRacing team

The UPMRacing team is made up of about 40 students from the final courses in the School of Industrial Engineering of the UPM, other UPM Schools such as the Aeronautic Techniques and Industrial Techniques Schools, and the Master in Automotive Engineering.

Currently UPMRacing has accumulated a wide

Table 1. Description of 2013 Formula SAE competition events [11]

Tests	Points	Description
Preliminary tests	**0**	Pre-competition safety tests.
Technical inspection	–	General check of car by judges.
Tilt	–	Car inclination up to 60^0 checking its stability and that no type of liquid is leaking.
Brakes	–	Simultaneous blocking of all four wheels after a brief acceleration.
Noise	–	Check to ensure vehicle emits less than 110 dB under certain acceleration conditions.
Static Events	**325 in total**	Presentations and oral defence in front of the judges of technical solutions adopted.
Engineering Design	150	Technical defence of vehicle design and solutions proposed.
Presentation	75	Marketing presentation, convincing the judges to choose their car compared with the others.
Cost Analysis	100	Written report detailing cost of each part and component of the unit built.
Dynamic	**675 in total**	Different on-track trials with the single-seater.
Acceleration	75	Cover 75 m on a straight run in the shortest possible time.
Skid-Pad	50	Manoeuvrability to run a 9 metre circle in both directions.
Autocross	150	Quick lap of the circuit.
Endurance	300	Overall vehicle performance and reliability in 22 laps of a circuit.
Efficiency	100	Minimum consumption in endurance trial.
TOTAL	1000	

ten years-experience with the same number of race cars that have taken part in: the 2004–2010 editions of Formula Student England; and the 2011–2013 editions of Formula Student Germany.

From the beginning, the project has been based on four principles that are a statement of the teaching method used: learn by applying; learn by doing; learn in a team and learn by competing. Moreover, in order to maximise student performance and progress, a whole strategy of learning situations has been planned, which participants must pass during their period in the team (Table 3).

Students remain in the team for two courses. In this way, during the first year they get comprehensive training in the technologies that they are going to need; and during the second year they begin the computer design of the vehicle which they will manufacture, test and finally compete with. All students take a short course in the different parts of the vehicle, so that they get an overview of it before choosing a division or area on which they are to be examined in-depth and which they will work on during their time in the team.

The UPMRacing team is organised into several divisions according to the main vehicle systems. These divisions, supervised by teaching staff, conform to an operative organisation. The main tasks of each division are presented in Table 2.

Another important point of project control is the tutorials and the periodic update meetings. Each student has to present the work that he has committed himself. The responsibility given to each student is real.

2.3 Professional competencies promoted by Formula SAE

From initial stages of the Formula SAE project, the teaching staff managing the UPMRacing team became fully aware of the importance of promoting personal and professional skills. The educational experience provided by taking part in this project and the teaching methods used mean that the student must face up to specifically designed situations that will challenge them and promote their personal and professional skills. Table 3 shows 16 different learning situations related to different moments or activities of the project, cross-referenced with 24 skills that, in the light of the literature consulted and the studies and surveys presented are deemed to be the most sought after in an engineer getting ready to work in the automotive sector [9].

After the ETSII was recognized with the ABET certificate (2010), the School of Industrial Engineers of Madrid established the list of generic competencies required by ABET for engineering programmes as the academic ones. The ABET competencies are the following:

(a) An ability to apply knowledge of mathematics, science and engineering
(b) An ability to design and conduct experiments, as well as to analyze and interpret data
(c) An ability to design a system, component, or process to meet desired needs
(d) An ability to function on multi-disciplinary teams

Table 2. Main tasks of each division in UPMRacing team [9]

Chassis and aerodynamics	Chassis design, modelling and building. Driving seat ergonomics and seat manufacture. Aerodynamic study and bodywork building. Crash calculation and simulation of front part.
Electronics	Engine control and ECU programming. Fitting sensors, data acquisition, management and telemetry. Wiring, switches, brake light, control panel on steering wheel.
Brakes	System requirements and components selection. Bench tests. Designing, calculating and manufacturing the uprights. Designing, calculating and manufacturing the pedal box.
Engine	Design, calculation and construction of the intake and exhaust system. Fuel tank and filler neck. Computer simulation and power bench.
Suspension	Study and design of A-arms, actuators and bell cranks. Choosing shock absorbers and designing stabiliser bars. Steering column geometry and rack location.
Transmission	Sprocket and housing support design. Selecting of differential, design of its housing and their support. Adapting axles and CV joints.
Vehicle Dynamics	Vehicle stability analysis in track performance. Racing strategies.
Organisation and Marketing	Setting up organisation, working methods, communications and information channels, and control procedures. Cost and budget control. Search for sponsors and presence in mass media.

(e) An ability to identify, formulate, and solve engineering problems
(f) An understanding of professional and ethical responsibility
(g) An ability to communicate effectively
(h) The broad education necessary to understand the impact of engineering solutions in a global and societal context
(i) A recognition of the need for, and ability to engage in life-long learning
(j) A knowledge of contemporary issues
(k) An ability to use the techniques, skills, and modern engineering tools necessary for engineering practice

During the period between 2010 and 2012, grading rubrics are being developed to help teaching staff for assessing these competencies. Nevertheless and as it is described below, the professors involved in the Formula SAE project have found difficulties for applying the rubric-based assessment to some of the competencies required by ABET. So a psychometric test-based assessment has been implemented during the 2011–2012 edition.

Table 3. Promotion of personal and professional skills according to different activities and learning situations [9]

Learning situations / Competencies	1. Initial training in all knowledge	2. Supplementary material .and in-process tutorial sessions	3. Division into subgroups according to work areas	4. Assigning duties, objectives and responsibilities	5. Organisation and planning according to general costs and	6. Students are responsible for their work and work together	7. Wide personal autonomy and possibilities for innovation	8. Periodic presentation and updating meetings	9. Resources search and usage management	10. All students take part in vehicle manufacture	11. Former students coordinate activities of newcomers	12. Participation in a real experience	13. Putting acquired knowledge into	14. Competing against the best world universities	15. Presenting and defending the work done in front of a panel	16. Need to disseminate the experience and the results
1. Ability to work as part of a team			X	X	X	X		X	X	X	X	X		X	X	X
2. Leadership qualities			X	X	X	X		X	X	X	X	X		X	X	X
3. Ability to motivate			X	X	X	X		X		X	X	X		X	X	X
4. Capacity for responsibility and commitment		X	X	X	X	X	X	X	X	X	X	X		X	X	X
5. Capacity for innovation				X		X	X			X		X	X	X		
6. Negotiating skills			X	X	X	X	X	X	X	X	X	X		X	X	X
7. Capacity for self-motivation	X	X	X	X		X	X		X					X	X	
8. Analytical skills	X	X	X	X	X	X	X	X	X				X	X		
9. Ability to summarise				X	X	X	X			X		X	X	X	X	X
10. Capacity for criticism and self-criticism		X	X	X	X	X	X	X		X	X	X	X	X	X	X
11. Ability for self-learning	X	X	X	X			X						X	X		
12. Organisational and planning skills		X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
13. Ability to identify problems			X	X	X	X	X	X	X	X	X	X	X	X	X	X
14. Ability to solve conflicts				X	X	X		X	X	X	X	X	X		X	X
15. Ability to generate new ideas (creativity)				X		X	X	X	X			X	X	X	X	X
16. Ability to take up new initiatives				X	X	X	X		X	X		X	X	X		X
17. Ability to adapt to changing circumstances	X		X	X	X	X			X	X	X	X	X	X	X	X
18. Ability to work on one's own	X	X		X	X	X	X						X			
19. Ability to make decisions				X	X	X	X	X	X	X	X	X	X	X	X	X
20. Interpersonal skills			X	X	X	X		X	X	X	X	X		X	X	X
21. Ability to assimilate and apply knowledge	X	X		X		X	X			X	X	X	X		X	
22. Capacity for dynamism				X	X	X	X		X	X	X	X		X	X	X
23. Capacity for discipline and self-control	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
24. Oral and written communication in English	X	X							X			X		X	X	X

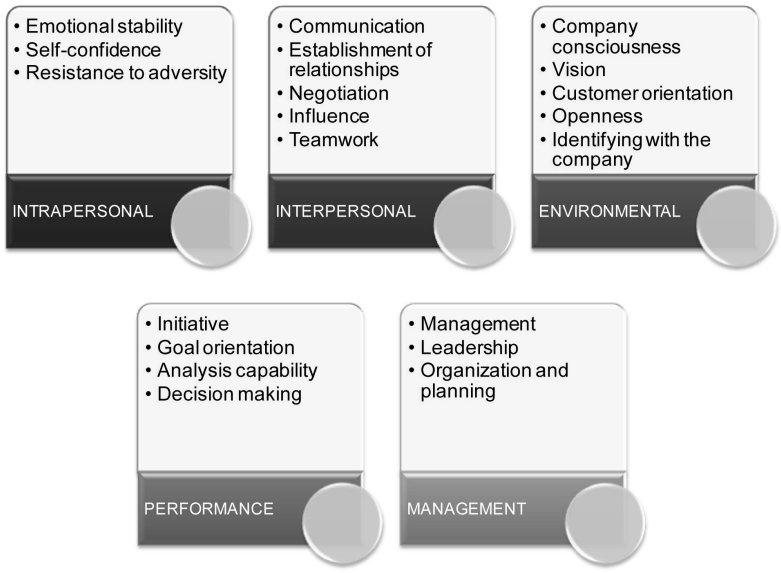

Fig. 1. The twenty competencies evaluated by compeTEA test as gathered in five global dimensions.

2.4 Assessment methodology of professional competencies promoted by Formula SAE

The assessment of students learning within team-based subjects is a challenging task, due to the high level of complexity inherent in the socially team-based learning environment. Team products, such as reports and presentations, by themselves provide insufficient evidence of the breadth and depth of an individual student learning.

Taking into account the learning methodology of the UPMRacing project, it is necessary to distinguish the improvement in the students professional competencies compared with traditional activities. Grading rubrics play pivotal roles in the assessment of professional competencies. The grading rubric prioritizes the learning outcomes and lists the level of evidence needed for each learning outcome in order to be awarded a particular grade.

From the beginning of the UPMRacing project, different grading rubrics have been applied for assessment the learning outcomes, especially after the ABET accreditation in ETSII. The use of the rubric by teaching staff is an objective grading tool, as well as the means to provide students with clear requirements for their project.

Nevertheless, the UPMRacing teaching staff has not received specific training for the assessment of professional competencies. So, they have found difficulties for applying the rubric-based assessment to some of the generic competencies required by ABET, mainly the ability to function on multi-disciplinary teams.

This paper shows the experience of introducing a psychometric test for assessment the professional competencies. The compeTEA questionnaire© has been selected to assess competencies in the context of the UPMRacing team. This questionnaire has been applied to the team members in two milestones: when they start their participation and after they compete.

The compeTEA questionnaire© is specifically designed to assess competencies in organizational context. It consists of 170 items to answer according to a 4-point Likert scale. Twenty different competencies gathered in five global dimensions can be evaluated by compeTEA, as it is shown in Fig. 1. Social desirability is controlled by means of a Sincerity scale that the questionnaire includes.

This assessment methodology has a broad and solid empirical support. Also, its double-interpretation system allows getting the normative score as well as the level of competence of the examinee according to behavioural frequencies. These features help to translate psychometric results to the language of competencies, and a higher accuracy and amount of information.

The compeTEA interpretation system considered in this paper (Table 4) has been the level of competence.

Table 4. Levels of competence as interpretation system of the compeTEA test

Level of competence	Description
0	Very low
1	Low
2	Medium
3	High
4	Very high

Fig. 2. The UPMRacing race car manufactured during the 2011–2012 edition.

3. Main results and discussion

The compeTEA questionnaire© has been applied to the 2011–2012 edition team members in two milestones:

- Pre-test: when they start their participation (September, 2011).
- Post-test: after they compete (September, 2012).

The total number of students completing the two-stage questionnaire has been 30 members, who have manufactured the race car shown in Fig. 2.

The compeTEA test is designed to assess twenty different competencies (Fig. 1) named as follows:

1. CTEA-EST: Emotional stability.
2. CTEA-CONFI: Self-confidence.
3. CTEA-RES: Resistance to adversity.
4. CTEA-COM: Communication.
5. CTEA-REL: Establishment of relationships.
6. CTEA-NEG: Negotiation.
7. CTEA-INF: Influence.
8. CTEA-EQUI: Teamwork.
9. CTEA-CONO: Company consciousness.
10. CTEA-VIS: Vision.
11. CTEA-ORCLI: Customer orientation.
12. CTEA-APER: Openness.
13. CTEA-IDEN: Identifying with the company.
14. CTEA-INI: Initiative.
15. CTEA-ORRES: Goal orientation.
16. CTEA-ANAL: Analysis capability.
17. CTEA-DECI: Decision making.
18. CTEA-DIR: Management.
19. CTEA-LID: Leadership.
20. CTEA-ORG: Organization and planning.

According to the scale of levels of competence (Table 4), the Fig. 3 shows the average level value (30 students) per compeTEA competency from the pre-test and post-test. From the previous values, the

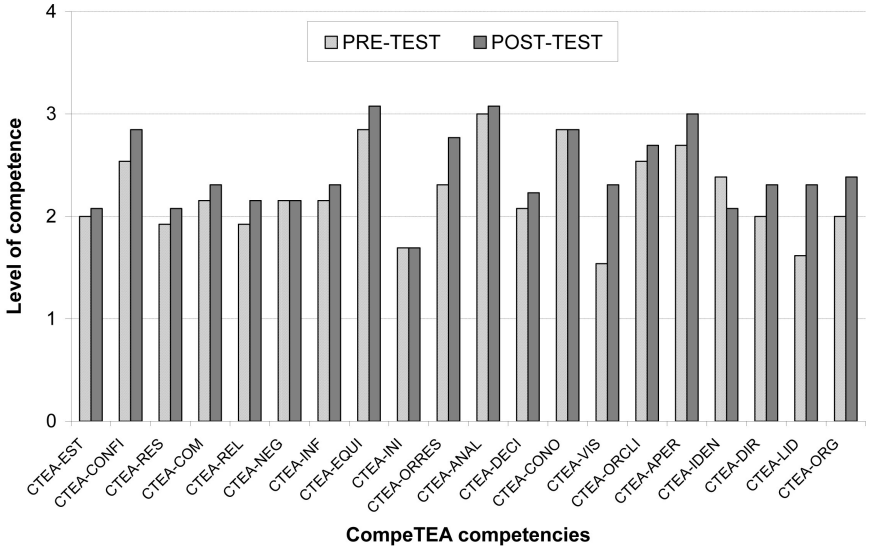

Fig. 3. Average value of the level of competence per compeTEA competency. Pre- test and post-test results.

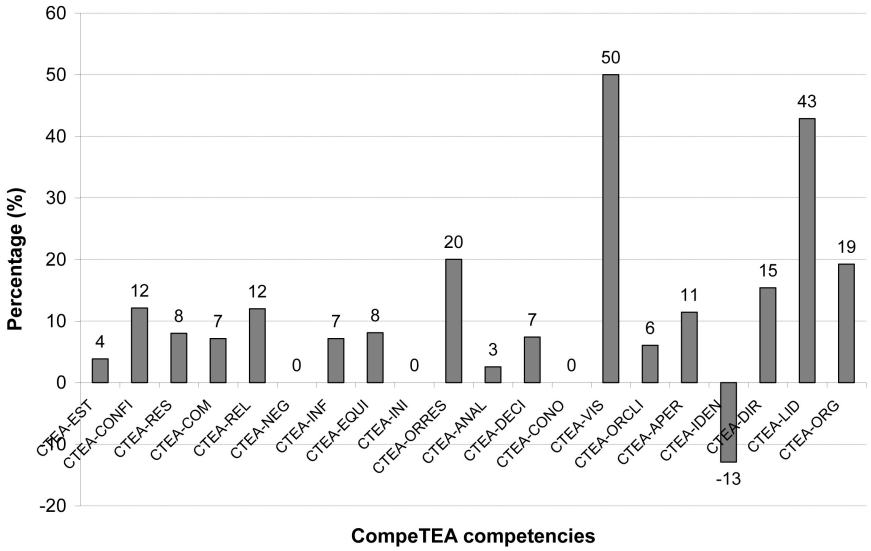

Fig. 4. Percentage change between the pre-test and post-test average level values per compeTEA competency.

Fig. 4 highlights the percentage change between the pre-test and post-test average level values per compeTEA competency.

The results conclude that this learning activity increases the professional competencies in a significant way: the 80% of the compeTEA competencies increases their average level for one year period of time. This effectiveness of learning is mainly noticeable in case of the students with the lowest level of professional competencies in the initial stage (pre-test), as it is shown in Fig. 5.

Three of the compeTEA competencies reach an average level around 3:

- CTEA-EQUI: Teamwork.
- CTEA-ANAL: Analysis capability.
- CTEA-APER: Openness.

CTEA-EQUI competency, as the ability to function on multidisciplinary teams, is one of the main targets of this project: learn in a team; and it increases its average level in a moderate percentage of 8%.

Related to the Formula SAE competition targets, the main deficiencies identified in the UPMRacing team members were the acquisition of organisational and planning competencies (CTEA-ORG: Organization and planning). Its average level in the initial stage is 2 and, as effectiveness of learning, this competency increases its average level in a percentage of 19%.

Another important competency in the team-based projects is the leadership (CTEA-LID: Leadership). The pre-test average level is less than 2.

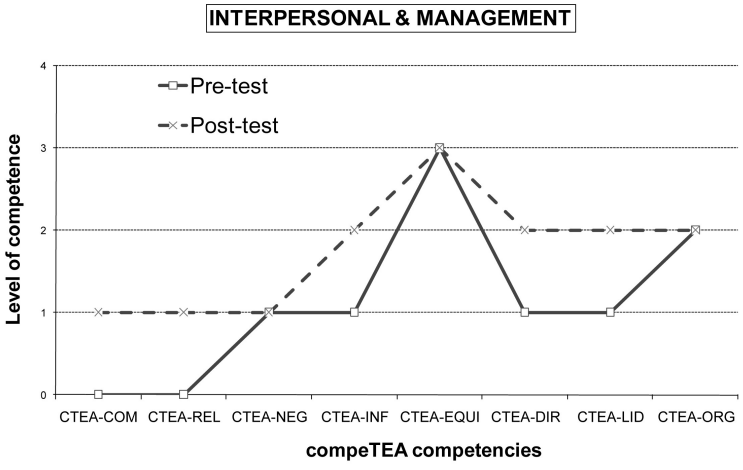

Fig. 5. Level of competence per compeTEA competencies for Interpersonal and Management dimensions. Pre- test and post-test results for a student with the lowest level of professional competencies in the initial stage.

Nevertheless, this competency increases its average level in a percentage of 43%.

The percentage change between the pre-test and post-test average level in four of the compeTEA competencies results null or negative:

- CTEA-NEG: Negotiation.
- CTEA-INI: Initiative.
- CTEA-CONO: Company consciousness
- CTEA-IDEN: Identifying with the company.

CTEA-CONO and CTEA-IDEN competencies are clearly related to company subjects, and they are not adequate for the student assessment. By other side, specific training about "Negotiation" is not included in the UPMRacing training program so the CTEA-NEG competency is not improved by this activity. The pre-test average level of CTEA-INI competency is less than 2 and it is not apparently improved by this project, so it is necessary to steer the learning process focused on the initiative competency as an important ability in the professional activity.

4. Conclusions

Pedagogical innovations in the field of the competence-based learning, such as the Formula SAE, require incorporating into the university strategic policies the ongoing training and updating of teaching staff, especially for the rubric-based assessment procedure.

This paper describes a trial to evaluate the adaptation of a psychometric test-based model for the professional competencies assessment. Although the compeTEA questionnaire© is not a tool developed for educational purposes, it seems adequate for the assessment of professional competencies during the Formula SAE project. The results conclude that this learning activity increases the professional competencies in a significant way, mainly in case of the students with the lowest level of professional competencies in the initial stage. The leadership competency level is improved in a significant value.

Additionally, the main deficiencies identified in the participating students were the initiative and the acquisition of organisational and planning competencies, so it is necessary to steer the learning process focused on these competencies as important abilities in the professional activity.

After the development of the assessment experience shows in this paper, a specific psychometric test for the assessment of personal and professional skills has been developed: the compeUPM test. This test is the main output from a research project funded by the Technical University of Madrid. The compeUPM questionnaire is specifically designed to assess competencies in engineering education.

From an academic point of view, the Formula SAE project serves for students to pass one of the two free choice subjects: "Application of Automotive Technologies I. Design" and "Application of Automotive Technologies II. Manufacturing". Free choice subjects are voluntary, although the student must choose from those offered by the university in order to cover the free choice ECTS credits. Only the 40% of students participating in this project selects one of these subjects per year. So, the student motivation is the improvement of professional skills rather than the credits compensation.

5. Future issues

The Formula SAE project increases the professional competencies in a significant way for one year period of time. Nevertheless, next steps will be focused on comparing this improvement in the level of professional competencies related to the level change in more conventional activities.

As it has been concluded, the main deficiencies identified in the participating students were the acquisition of organisational and planning competencies. The research project IE12 13-05015, funded by the Technical University of Madrid, is incorporating new learning activities in 2012–2014 editions of Formula SAE teams, directed towards the correction of these deficiencies.

Psychometric tests seem adequate for the assessment of professional competencies. The compeUPM questionnaire, specifically designed to assess competencies in engineering education, will be introduced as an assessment tool in 2013–2014 edition of Formula SAE team, as a specific topic in the research project IE12 13-05015. Another important topic evaluated in this project will be the minimum period of time needed between pre-test and post-test.

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