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Spatial Ability in Computer-Aided Design Courses

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ABSTRACT

Many studies have demonstrated that spatial ability is an important factor in the study of Industrial Engineering. Spatial ability is fundamentally important to the work of an engineer, as it is vital for project design. Among other elements, spatial ability correlates with factors such as good academic results and a natural ability to learn how to use I.T systems and computer programs. Furthermore, the new framework drawn up by the European Higher Education Area (EHEA) guides us as to the definition and measurement of the aforementioned competencies, among them spatial ability. In this paper we will consider the improvement of spatial ability through the use of 3D solid modeling software. Our study was undertaken with 812 students of first year Industrial Engineering at the Universitat Politècnica de Catalunya. The evolution of the scores they obtained on the Differential Aptitude Test - Spatial Relations Subset (DAT-MR.) and the Mental Rotation Test (MRT) were analyzed both before and after taking a module on computer aided design.

This study attempts to develop a model which will allow us to evaluate the spatial ability (SA) of engineering students studying the first year module "Graphic Expression and Computer-Aided design".

Keywords: Computer-Aided Design, spatial ability, engineering education, engineering students, competency based education.

1. INTRODUCTION

Human intelligence shows itself through the development level of various competencies (verbal, numerical, spatial, etc.).

Many authors emphasize [17] the importance of spatial ability (SA) in the design process of engineering, and propose educational strategies to encourage the development of this competency among students. The development of spatial ability has long formed part of the Graphic Engineering curriculum [9]. In the last few years, interest in this area has been growing due to new developments and the impetus taken by graphical computer science. The relation between SA, the design process and graphic communication is what marks this study as important.

The concept of SA covers a wide array of cognitive functions. There are currently several tests which allow us to focus on the different components of this competency, such as spatial relations or spatial orientation [18]. This means that the concept of SA is fragmented into multiple sub-factors and that it is difficult to find a definition which is unanimously accepted by the entire scientific community.

However, we found two basic components of the competency that are accepted by the scientific community [9]:

Spatial vision: the ability to manipulate an object in an imaginary 3D space to create representations of the object from different points of view.

Spatial orientation: this refers to the capacity to navigate our surrounding environment and predict the movement and position of objects.

An engineer must be able to solve the representation of complex structures and systems [2] which arise in the development of his or her work using graphics. This is why SA is useful and can be vital in the development of engineering projects, as pointed out by various studies [5,17]. In the first stage of project design it is fundamentally important to resolve any problems in which space reasoning plays a decisive role quickly, for example in the sketching phase.

Furthermore SA has been recognized as a determining factor in the prediction of success many fields, but more especially in areas relating to technology [17]. That is to say, positive correlations have been

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established between SA and the academic results of engineering students. Positive correlations have been established between SA and the ease with which students learn to use computer programs or CAD tools, design data bases or develop molecular structures [13].

Learning to use a professional CAD tool, while studying Industrial Engineering, is ever more important due to the demands of the labour market. Consequently the great majority of universities and technical schools use a CAD tool in their first year engineering courses. In a fast-moving technological world, applications being heralded by learning technologists in higher education are constantly being overtaken by new ones [8].

Several authors [4,16] have demonstrated that the use of CAD tools can harness the development of spatial vision.

In summary, the importance of SA is the following:

- It is a basic competence any engineer needs to know.
- SA is fundamentally important for any project: SA is vital in the design and development of projects.
- Among other elements, spatial ability correlates with factors such as good academic results and a natural ability to learn how to use I.T systems and computer programs.
- An engineer must be able to solve the representation of complex structures and systems which arise in the development of his or her work using graphics.
- It is a determining factor for predicting success in diverse areas, but especially in the fields of technology and science (for example the positive correlations between SA and the academic results of engineering students).
- Positive correlations have been established between SA and the ease with which students learn to use computer programs or CAD tools, design data bases or develop molecular structures.
- The relation between SA and the ability to work with computer information systems (navigation of hierarchical menus and databases, e-learning portals, information storage systems and generally all types of internet spaces).

This study attempts to develop a model which evaluates the SA of engineering students studying the first year module "Graphic Expression and Computer-aided Design".

Our model will consider the methods and indicators necessary for its application, and will allow for consideration of the key variables in addition to suggesting what would most improve teaching methods.

Our objective is to verify whether or not the use of 3D modeling software, such as Solidworks, develops SA in students.

To achieve this, the students will took two different SA tests at the beginning and end of the semester. Any significant differences between the scores they obtained before and after the classes were noted.

This way we will be able to study whether or not the intervention made during the course produces an improvement of SA.

The study was undertaken during a period of important changes, as the module "Graphic Expression and Computer-Aided Design" has been modified to comply with the Bologna agreement. The integration of the universities into the European Higher Education Area (EHEA) leads us to modify the structure, content and education/learning model of our teaching programs. This gives a new aspect to the investigation.

The EHEA framework guides us on the definition of competencies: The formative activities have a formative-practical focus, which put the focus on acquiring the competencies specific to each module.

Evaluation of the results: The evaluation of the results must be in terms of competencies, to try to close the gap between academic and professional engineering by observing the knowledge and skills needed in the working world.

Integration into the European Higher Education Area gives us a definition of the competencies which are crucial to both the module of Graphic Expression and DAO. As we have previously mentioned, one of the most important competencies for an engineer and for the module is SA. Therefore the definition and evaluation of this competency is another important objective of our investigation. A scheme of investigation can be seen in Figure 1.

2. OBJECTIVES

The final objective of the study is to develop a model that allows us to evaluate SA in the students of Industrial Engineering and which allows us to evaluate the strategies and methods of the educational program in relation to SA.

This study aims to develop a model to evaluate the SA of engineering students studying the first year module, "Graphic Expression and Computer-Aided Design".

Our subject group is made up of 800 students of the UPC Engineering Faculty. The investigation is centred on the module content of "Graphic Expression and Computer-Aided Design" (GECAD) and on the study of the spatial abilities developed in it.

We are creating a model that measures any improvement of SA in the context of the module GECAD and allows for statistical analysis of the results.

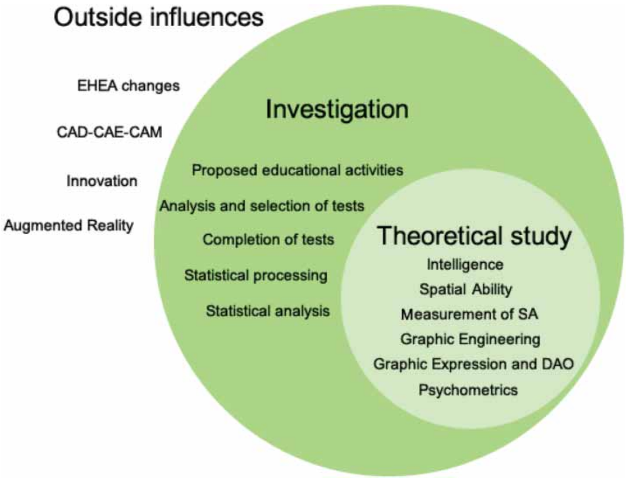

Fig. 1: Scheme of investigation.

This model could be applied to assess successive students and, with the necessary adaptations, students in other higher education institutions.

In addition, the study brings us to define a new plan for the module GECAD within the EHEA. This new EHEA framework guides us on defining and measuring competencies. As we have previously mentioned, one of the most important abilities in the overall academic formation of an engineer, particularly in the module GECAD, is SA.

3. METHODOLOGY

In this paper the field investigation, carried out with the DAT and MRT tests, is combined with documentary research.

We used a quasi-experimental design for the investigation, as we could not randomly assign the elements of the groups in the inter-subject strategies, nor could we control the order independent to an inter-subject strategy.

Our design was applied to a group who were evaluated by the DAT-SR and MRT tests before and after the studying the module GECAD. An example of an MRT test can be seen in Figure 2. We analysed the relation between the elements that were decided on in the hypothesis with a high control of variables.

The scientific methodology that was used also features in the investigation [1], since we defined specific actions, measured them and finally evaluated performances based on the results. Concretely, we intervened in the process by making decisions, and ended up specifying a model.

The model was used in order to verify whether or not the teaching methods in the module result in a significant development in the SA of students.

SA was measured through the results of the tests we used. From these results, we chose the type of test that was best adapted to the objective of our study.

Two tests were used in numerous studies in this field, which means that their inclusion in this study assures comparisons can be made [4,16]. In the type of studies in which aptitude tests are used, it is particularly important to make comparisons between similar test subjects, as otherwise notable differences can occur.

With this objective in mind two tests were used to analyse SA (DAT and MRT), at the beginning and end of the semester. Any significant differences between the results before and after the module will be statistically analysed.

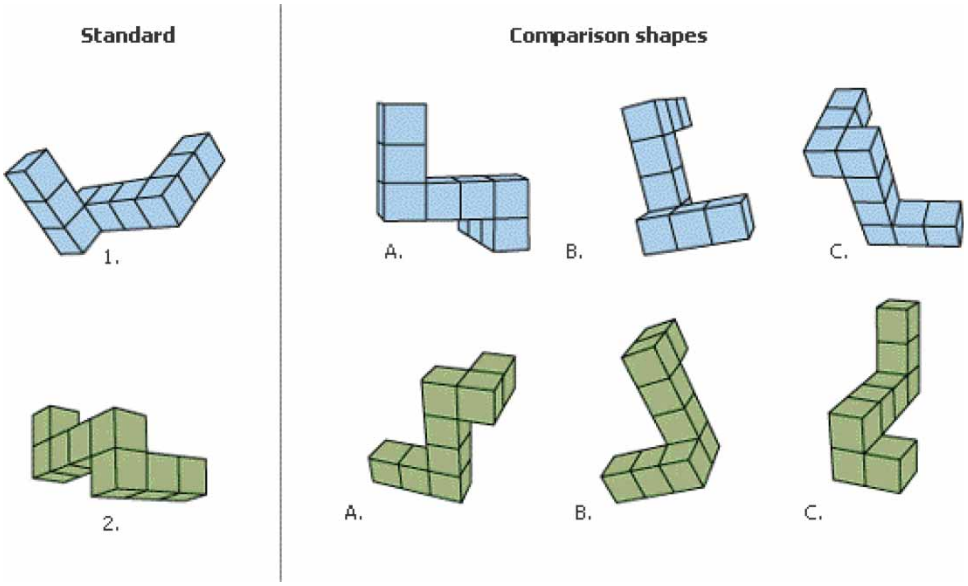

Fig. 2: Figure rotation (based on MRT).

SPECIFIC COMPETENCIES	C. CROSS-SECTIONAL T.I: Instruments; T.P: Interpersonal T.S: Systemic
COMPETENCIES RELATED TO BASIC CONCEPTS AND KNOWLEDGE	
C.1 Understanding, managing and applying a wealth of knowledge about the foundations and normalization of Industrial Engineering Drawing, a necessary skill in order to approach the problems of graphic engineering.	T.I.2. Capacity for analysis and synthesis T.I.3. Capacity for information management T.I.5. Basic knowledge of the profession T.S.2. Independent learning
C.2 The ability to use DAO programs with skill. This means using the computer as a learning tool to prepare the documentary base with the objects that need to be represented, from the knowledge gained from Engineering Drawing.	T.I.6. Knowledge of computer science T.S.2. Independent learning
COMPETENCIES RELATED TO CONSTRUCTIVIST LEARNING	
C.3 Managing and applying spatial capacity using sketching for support, within a framework of cognitive strategies development that helps the 3D visualization of technical objects.	T.I.1. Problem solving T.S.2 Independent learning
C.4 Interpreting and making standardized drawings from Industrial Engineering Drawing.	T.I.1. Problem solving T.S.1 Capacity to apply knowledge in practice T.S.2. Independent learning
C.5 Applying procedural knowledge to resolve problems regarding the representation of surfaces in Construction Geometry.	T.I.1. Problem solving T.S.1. Capacity to apply knowledge in practice T.S.2. Independent learning
C.6 Applying investigative skills and creativity in the introduction to industrial design.	T.I.1. Problem solving T.S.1. Capacity to apply knowledge in practice T.S.2. Independent learning T.S.3. Creativity T.S.5. Investigative ability
C.7 Managing information sources, setting out and justifying through graphics, as well as spoken and written form the aspects relating to design ideas and to the interpretation and creation of engineering documents.	T.I.4. Ability to organize and plan T.I.7. Spoken and written communication, and communication through graphics
C.8 Teamwork that results in broadening knowledge through critical exchanges.	T.P.1. Teamwork T.P.2. Critical and self-critical ability

Tab. 1: Specific Graphic Expression and DAO competencies and their relation to integral competencies.

4. SPATIAL ABILITY AS A COMPETENCY

The definition and evaluation of competencies forms an important part of the EHEA (see Table 1).

A competency is an ability learned in order to carry out a task, responsibility or role. A high level of competency is a prerequisite of executing a task well.

Navío [11] writes that professional competencies combine elements which are formed through personal skills and personal and professional experience. These competencies are revealed through certain behavior in a professional context.

Among others, Moon's work [10] stands out for the outlined module programme and Urrazza's work [19] stands out as he proposes a model for integrating competencies, including SA, into a module:

5. RESULTS

In this study a model is used to measure any improvement to spatial ability, a basic competency for engineers.

The results show a clear increase in SA, which leads us to conclude that the teaching methodology used in the module favors the training of SA.

As we can see in Table 2, the increases are substantial, especially in the case of DAT, where we found between an 8 and 10% growth. We obtained improvements of 20% in most of the groups.

Obviously the groups with initially low scores have more potential to improve, but the increase in the averages is equally significant.

Analyzing the results, two of the expectations the majority of the professors had were fulfilled. In the engineering branch of mechanics were usually the best students, while the chemistry students usually had the most difficulties. This is particularly true in the DAT results.

The data shows a slight improvement among the students who play sports. In the final DAT in particular the difference is doubled between those who play sports and those who do not.

We can also conclude that the use of 3D modeling software together with the module activities encourage the development of SA, since a large part of the

Faculty	Average scores		(Standard deviation)	
	First MRT	Final MRT	First DAT	Final DAT
EUETIB*	21.74 (7.78)	28.6 (6,9)	39,5 (11.9)	47.48 (10,33)
ETSEIB**	23,8 (9.03)	30.0 (5,51)	45,47 (11.38)	50.9 (10,53)

*EUETIB. Escola Universitària d'Enginyeria Tècnica Industrial de Barcelona
**ETSEIB. Escola Tècnica Superior d'Enginyeria Industrial de Barcelona

Tab. 2: Comparative results between MRT and DAT tests.

	Controlled variables
1	Age
2	Sex
3	New/Retaking student
4	Engineering branch
5	Route of entrance into the university
6	Working while studying
7	Previous years studying drawing
8	Previously familiar with CAD software
9	Sport practiced by the student
10	Video game player
11	Favorite video game type
12	Internet user
13	Right or Left-handed
14	Faculty of Engineering

Tab. 3: Controlled variables in the study which have an effect on SA.

work in the module was done using 3D modeling software (Solidworks).

In this way SA is integrated in with the transversal competences of problem solving and self-regulated learning [12].

The selection of variables used is based on the theoretical study we conducted (see controlled variables in Table 3). If we review similar studies we will find these variables as critical in SA results. It allows comparisons with other studies and points to what actions to take in order to improve SA.

Through an analysis of the data we were able to cut down the list of variables we had considered during the investigation, selecting those which were most significant and therefore important to SA scores.

- Use of CAD software: significant differences in the students with experience in this type of programs are shown.
- Engineering branch: we found important differences between the engineering branch of the students, especially in chemistry, which obtained the lowest averages.

If we analyze the distribution of scores by taking the DAT test as a reference point, the minimum value we found was around 12 points while the maximum was 57. 60% of the test subjects find themselves between the average intervals of 28-47. Therefore we understand the results to be significant when they include 60% of the test subjects and above. 22% of the students are located in the inferior interval of 12-27, whereas 17% of the rest are found in the upper interval from 47 to 60.

For the students who in the inferior interval (<27) we propose revision sessions. The objective of these sessions at the beginning of the course would be to even out the level of the group so that any differences in development are not blamed on SA.

We considered at this point if some relation exists between the results obtained in the measurement of SA and academic results. We looked for a link between students' test scores and the marks they received on the module, which gave us a means of measuring the academic result of the different didactic activities we proposed. Table 4 shows SA values and academic results used in the correlations. We want to determine which didactic activities have a greater influence on the improvement of SA and implement a system that evaluates this improvement. The correlation between the values of SA and academic results is determined by an evaluation of the main teaching methods.

These correlations allow us to determine the influence of the educational methods used to improve SA, and they allow is to recognize the more efficient activities.

The strongest links were found with the DAT, which offers us values of R higher than 0.3.

The first DAT test with the DAO2 test is highlighted as it has a standardized coefficient Beta value of 0.37 (see Table 5 and Figure 3).

Within the hypotheses we proposed at the beginning, the strongest link is found between the first DAT and the exam on spatial geometry. Therefore we propose to harness the potential of the activities related to spatial geometry in order to maximize the development of SA.

DAT seems to be a good indicator of success in the module since it shows the highest amount of correlations.

MRT is not a useful measuring tool as it does not show any significant differences in any of the comparisons we made.

Scores obtained on the test		Evaluated activities in the subject
Score first DAT	MARK	Final mark for the module.
Score final DAT	DAO-1	Normalization exam
Score first MRT	DAO-2	Spatial geometry exam
Score final MRT		Final project mark
		Evaluation of the project by the professor.
		Evaluation of the project proposal by the professor.
		Evaluation of the project proposal by the student.
		Absences
		Theoretical questions
		Solidworks Tutorials.
		Sketchbook

Tab. 4: SA values and academic results used in the correlations.

The statistical studies allow us to obtain quantitative values that can be used as a reference for the quality indicators. Thus, the quantitative data derived from the results of the test allows us to select and improve the methods that increase SA. In addition they contribute to determining the reliability of the surveys.

	Non-standardized coefficients		Standardized coefficients		
	B	Standard error	Beta	T	. Sig.
first_DAT	.077	.012	.368	6.726	.000

Tab. 5: First DAT compared to DAO2.

At the same time, the study shows the results of a change to the EHEA and ECTS systems, under cooperative and constructivist teaching methods.

Curriculum designs which allow for comparisons between the students' results and previous statistics and a further method to improving teaching standards are viewed very positively.

The model provides us with:

- A refinement system for the variables
- A system to test new work methodologies

Finally, all of the data relates to the decisions we took in order to improve teaching quality, as we have at our disposal a set of methods and tools with which we can compare records with reference indicators in a process of continuing improvement.

With respect to the analysis of the student satisfaction survey we can say that:

The most favorable evaluations the students gave were in the subject knowledge of the teaching staff, and in their interest in the subject. The DAO subject

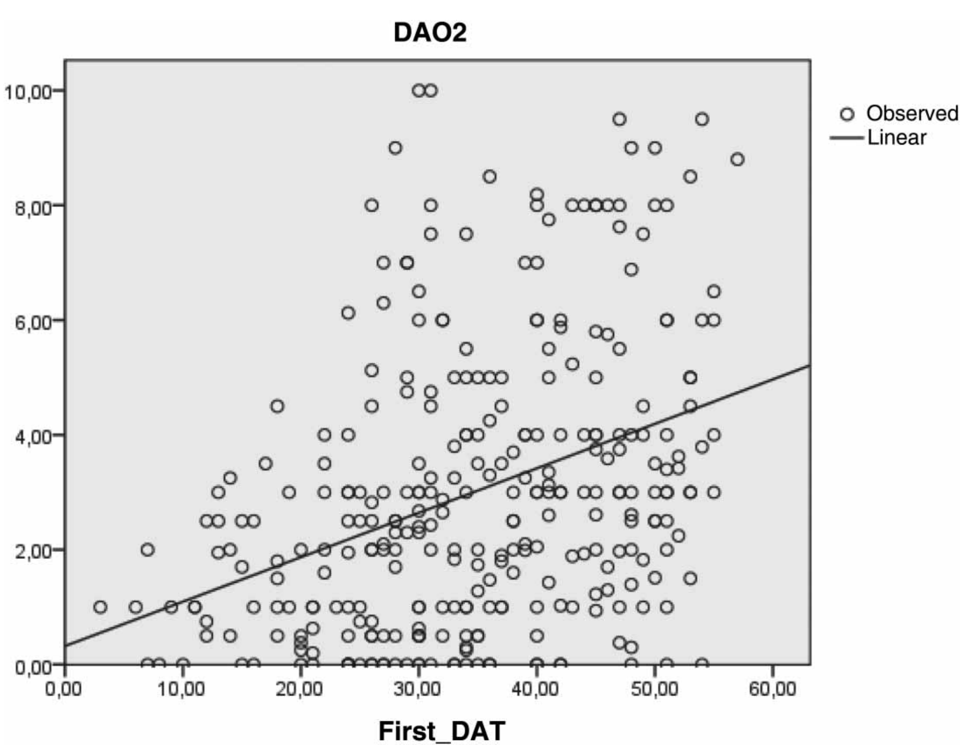

Fig. 3: First DAT compared to DAO2.

was popular among students, although the difficulty and effort required in the subject brought some of the indicators down.

The high evaluation of the group project work also stands out. The project forces the students to cope with a real life project, a situation which makes them grasp many new concepts. They are conscious of this fact and they value it very positively in the surveys [7, 14].

Also, the students seem to be satisfied with the weekly guided tutorials. These tutorials cover a range of the uses of modeling software, which is an important element of their learning.

On the other hand, the lowest values are found in the weekly exams and in the opinion we hold of the students dedication. This is a topic which is often discussed between students and professors. The module requires dedication, and the demands of a weekly exam force the students to maintain a high level of work. A complaint about this is reflected in the survey.

At the same time, one of the aspects with the highest scores is the volume of work on the subject, something reflected in the previous comments.

6. MODEL

We defined a model for the development of SA in the Graphic Expression subject (see Figure 4).

The objective of the model was to have resources for improving the quality [15] of teaching on SA. The model allows for the control of variables that affect SA and allows us to measure it before and after the academic year. In addition, the model establishes relations between educational methodologies, academic results and student satisfaction. [3,6].

Our subject group is made up of 800 students from the Engineering Faculty of the UPC. The investigation is centred on the subject content of “Graphic Expression and Computer-Aided Design” (GECAD) and on the study of the spatial abilities developed in it.

In this study a model is used to measure any improvement to spatial ability, a basic competency for engineers.

In order to achieve this, the variables which have an effect on SA are described, and a system is proposed to sort through the variables in order to discover which teaching methods improve SA scores.

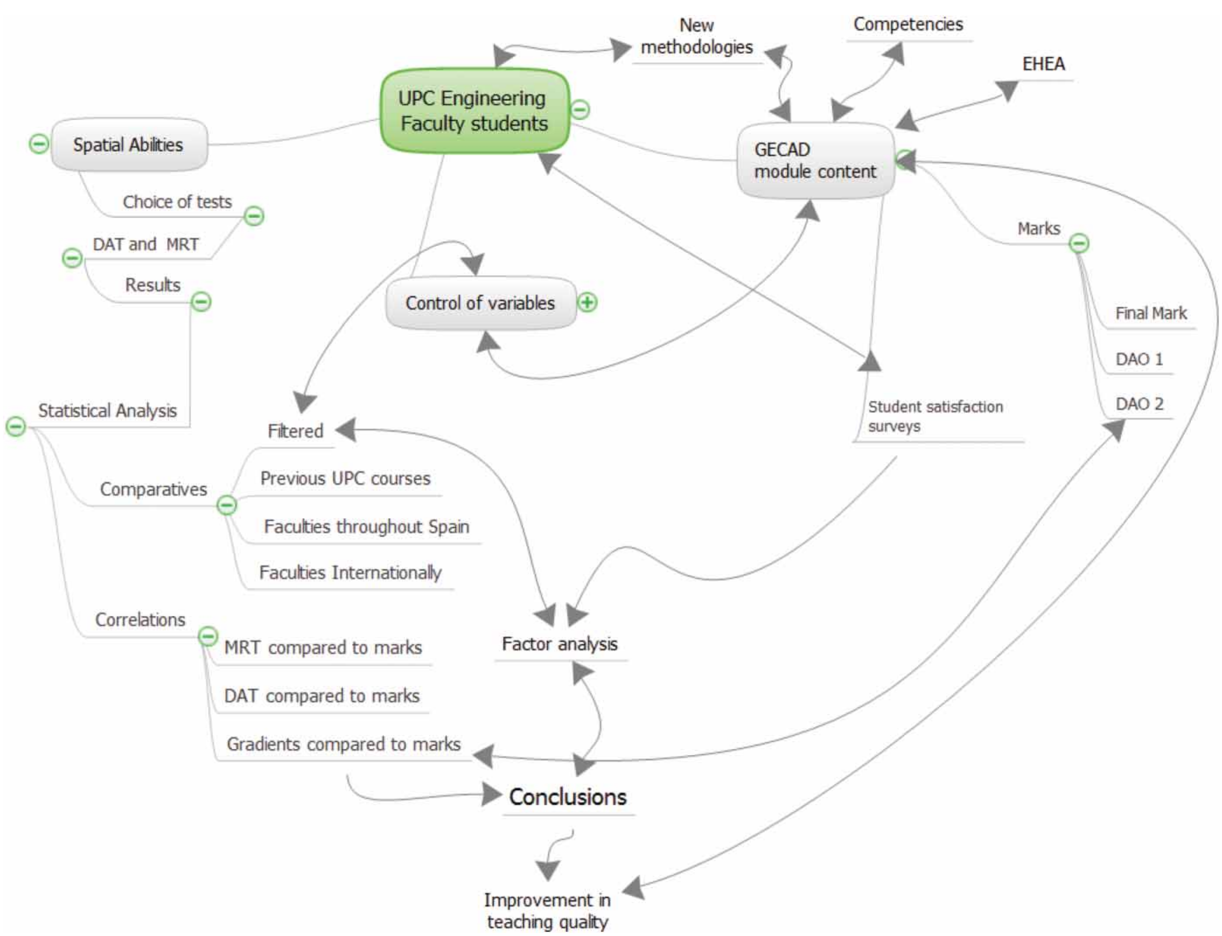

Fig. 4: We defined a model for the development of SA in the Graphic Expression subject.

Correlations	Comparisons
MRT in comparison with marks	With a filter of the variables
DAT in comparison with marks	Previous academic years at the UPC
Gradients versus marks	Faculties throughout Spain
	International Faculties

Tab. 6: Indicators.

The statistical studies allow us to obtain quantitative values that can be used as a reference for the quality indicators. In addition they contribute to determining the reliability of the surveys.

The correlation between the values of SA and the academic results of the students is determined by the evaluations of the main educational activities. These correlations allow us to determine the influence of the educational methods used to improve SA, and they allow us to recognize the more successful activities.

Finally, all of the data relates to the decisions we took in order to improve teaching quality [7], as we have at our disposal a set of methods and tools with which we can compare records with reference indicators in a process of continuing improvement (see quality indicators in Table 6).

7. CONCLUSIONS AND FUTURE LINES OF INVESTIGATION

The results show a clear increase in SA, which leads us to conclude that the teaching methodology used in the module favors the training of SA.

The increases are substantial, especially in the case of DAT, where we found between an 8 and 10% growth. We obtained improvements of 20% in most of the groups.

Obviously the groups with initially low scores have more potential to improve, but the increase in the averages is equally significant.

Analyzing these figures, two of the expectations the majority of the professors had were fulfilled. In this module the mechanics were usually the best students, whereas chemists were usually those who had more difficulties. This was shown in the results of the DAT.

The data shows a slight increase in ability in the students who play sport. This is especially true in the final DAT test where students who play sports have much better results. Therefore playing sorts can be an important variable to consider.

We can also conclude that the use of 3D modeling software together with the module activities encourage the development of SA, since a large part of the work in the module was done using 3D modeling software (Solidworks).

In this way SA is integrated as a competency with the cross-sectional abilities of problem solving and independent learning.

In order to achieve this, the variables affecting SA are described and a system to refine the variables is proposed which will direct us to the actions to take for improving SA.

Of all the variables studied, the following variables stand out through the results analysis as fundamental to the SA test scores:

Use of CAD software: significant differences in the students with previous experience of this type of programs are shown.

Engineering branch: we found important differences between specialities, especially in the case of chemistry, which obtained the lowest averages.

The strongest link we found was between the first DAT and DAO2, relating to spatial geometry. Therefore, we propose to harness the potential of these activities with spatial geometry in order to maximize the development of SA.

DAT seems to be a good indicator of success in the module since it shows the highest amount of correlations.

MRT is not a useful indicator as it doesn't result in significant differences in any of the comparisons.

Some of the possible future lines of investigation are:

- Comparing the indicators obtained with records in a process of continual improvement.

Test Results: Increases in the DAT, comparisons internationally and nationally, age, academic performance and the relation between DAT and the final degree mark, DAO1 and DAO2.

- Completing the model with the measurement of other competencies that are fundamental in the field of engineering. Furthermore, applying the model to improve teaching methods by incorporating and assessing new methodologies by comparing academic results to the acquisition of skills.

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