International Journal of Engineering Education Vol. 33, No. 2(A), pp. 680–692, 2017
Printed in Great Britain
0949-149X/91 $3.00+0.00
© 2017 TEMPUS Publications.

Factors Influencing Spatial Skills Development of Engineering Students*

JESÚS MATAIX, CARLOS LEÓN and JUAN F. REINOSO
Advanced Technical School for Civil Engineering, Department of Graphic Expression in Architecture and Engineering, University of Granada, Av. Severo Ochoa s.n., 18071 Granada, Spain. E-mail: jesusmataix@ugr.es; cleon@ugr.es; jreinoso@ugr.es.

Spatial skills are fundamental not only for engineers and architects but also for professionals in a great variety of fields. These skills are crucial also in the academic training of students of all ages. In the academic year 2012–2013, a large-scale study was made at the University of Granada (Spain) to evaluate the influence exerted on these skills by several factors related to personal aspects, experience, hobbies, and abilities. At the beginning of the term, a spatial test and a questionnaire were administered to 750 students in three majors (Bachelor's degrees in Civil Engineering, Chemical Engineering, and Industrial Electronic Engineering) who were studying courses on Graphic Expression. During the semester, the students were invited to participate in a set of voluntary spatial skills training activities based on exercises of freehand sketching. At the end of the term they were administered a spatial test again. General intelligence, problem-solving ability, gender, construction games, and experience in technical drawing are the factors more directly related to spatial skills. Furthermore, the training activities have shown a high degree of effectiveness in improving the students' spatial skills.

Keywords: spatial skills; spatial visualization; factors influencing; academic training; curricula

1. Introduction

1.1 Importance of spatial skills

Graphic expression and spatial skills are fundamental tools to pursue a profession in Engineering and Architecture. These are indispensable for any designer and enable the graphic transmission of the design among all the agents involved in the design, construction or manufacture of a building, other structure, or machine, etc. Also, these skills are crucial in academic training, for example in learning graphic expression, in problem solving, or in understanding scientific concepts, in addition to boosting the general confidence level of students and improving the probability of success in their studies [1].

However, the importance of spatial skills is not limited to Engineering and Architecture. Many studies have related them to a wide variety of fields of knowledge. For example, Smith [2] identified up to 84 different majors in which spatial skills play a relevant role, such as sciences in general, mathematics, chemistry, medicine, and even music.

Numerous researchers have shown the need for paying closer attention to visual thought and spatial skills at all levels of the educational system [3–8]. Nevertheless, in recent decades, graphic expression and spatial skills have been steadily losing prominence in study planning [9–11].

1.2 Research on factors influencing spatial skills

One important field of research concerning spatial abilities is related to the factors that influence their acquisition and development. In this field, studies can be classified into two broad categories: (1) those that seek to evaluate to what extent spatial skills can be related to diverse factors of the biological, environmental, psychological type or those linked to life experiences; and (2) those that focus on determining whether it is possible to train spatial skills and what is the best manner to do so.

Most studies of the first type concentrate on a specific factor, studying samples of variable sizes. The most frequently analysed factor and the one that has been investigated with the largest sample sizes, is undoubtedly gender. In this sense, Cochran and Wheatley [12] studied 165 students, Hamilton [13] 176, Pearson and Ferguson [14] 282, and Lunneborg [15] 780, for the largest-scale study. In terms of studies of the second type, the sample sizes tend to be considerably smaller, with generally fewer than 50 students and rarely more than 100.

In its research field, the study described in the present paper stands out for its sample size (871 students) and for the great quantity of factors analysed (a total of 19, corresponding to personal traits, abilities, experiences, and hobbies).

Age is perhaps the factor most closely related to spatial skills. According to the studies of Piaget [16], spatial abilities are developed in several stages over childhood and adolescence, a conclusion which has been analysed and confirmed in a multitude of later studies. Other studies, such as Pak [17], appear to indicate that these skills deteriorate with age during adulthood. In terms of gender, many studies have analysed the influence of sex on the STEM fields

* Accepted 4 December 2016.

(Science, Technology, Engineering, and Mathematics) [18, 19]. It is practically unanimous that males surpass females in spatial tasks and that these differences are persistent and cross land borders [20, 21], although there are also authors that argue that these differences are diminishing or that they do not exist at all [22, 23]. Diverse biological, environmental, and psychological factors have been analysed as the possible causes of the gender differences in spatial abilities. Some studies relate these differences to the inequality between males and females in professions related to Engineering and with the Sciences in general [1, 24, 25].

Although age and sex are the factors most closely associated with spatial skills, many other parameters have been studied. Positive correlations have been found with features such as: general intelligence, more specifically the type of mental strategy used in spatial tasks [26]; playing with construction games during infancy [27, 28]; musical skills [29, 30]; practice of certain sports [31]; playing three-dimensional video games [32]; prior experience with technical drawing; mathematical skills [28]; freehand sketching skills [33]; etc. It should be highlighted that there is no complete consensus on the relation of these factors, and many studies with highly diverse experimental conditions have drawn contrasting conclusions.

Other factors such as hand preference, the profession of the parents (particularly if related to Engineering or Architecture), and the ability to operate a computer and certain computer applications, have been demonstrated to have a doubtful relation to spatial abilities.

Finally, in relation to the training of spatial abilities, a great number of studies have concluded that these skills can be significantly improved by specific training and that the methodology that affords the best results is the one that requires the student to adopt an active role in solving spatial problems using a pencil and paper [34, 35].

1.3 Objectives of the study

The overall objective of the present study is to analyse the influence exerted on spatial skills by a broad set of factors, examined to a greater or lesser extent in other works using samples of highly diverse sizes and nature and widely differing experimental conditions, but here using a single and extensive sample and a homogeneous methodology.

For this the following specific objectives were laid out:

- To analyse the relation between the spatial skills of the students and certain personal features (age, gender, hand preference, and profession of the parents in relation to Engineering or Architecture), experiences and hobbies (to have attended a course in technical drawing, to have played with construction games during childhood, to have played video games, to have practiced sports in general or sports with a spatial component, experience with graphic-design programs, and mastery of any musical instrument), and the student's perception of his or her own skills (general intelligence, spatial visualization, problem solving, imagination, mathematics, freehand sketching, computer use, affinity for music).
- To analyse whether the perception that a student has of his or her own spatial abilities constitutes a reliable indicator of those abilities and therefore could serve in the decision concerning whether or not to perform specific training activities.
- To analyse the effectiveness of the training activities for spatial skills designed for the study, and to test whether this effectiveness is the same in students with different starting levels of these skills.

2. Method

2.1 Methodological strategy

The present study is quantitative and correlational [36], as it is based on data collection and subsequent statistical analysis with the aim of determining the factors significantly related to spatial skills in Engineering students.

The research design is fundamentally non-experimental, since the majority of the data analysed refer to features of the students which the researchers do not influence. However, the study also includes an experimental part, meant to evaluate the effectiveness of the spatial skills specific training activities.

2.2 Population and sample

The study was made with students in five courses of Graphic Expression of three technical majors at the University of Granada (Bachelor's degrees in Civil Engineering, Chemical Engineering, and Industrial Electronic Engineering) during the second term of the academic year 2012/13. A total number of 871 students were enrolled in these courses.

2.3 Data collection instruments

The information related to the characteristics of the students was compiled through a voluntary questionnaire administered at the beginning of the term, requesting personal traits (age, sex, hand preference, and profession of the parents), experiences and hobbies (Technical Drawing courses, construction games, video games, sports with a spatial component, sports in general, graphic-design programs, and musical instruments) as well as an evaluation of their own skills (general intelligence,

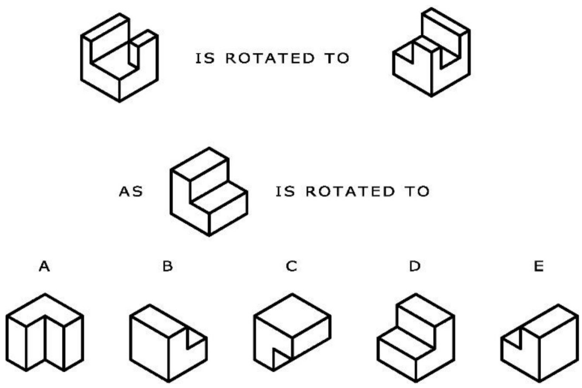

Fig. 1. Reproduction of an example item from the *Purdue Spatial Visualization Test: Rotations* [38].

spatial visualization, problem solving, imagination, mathematics, freehand sketching, use of the computer, and affinity for music). A total of 726 students filled out the questionnaire either partially or completely.

For the evaluation of the spatial skills of the students at the beginning and end of the term, the *Purdue Spatial Visualization Test: Rotations (PSVT:R)* [37] was used, in its reduced version proposed by Bodner and Guay [38]. This test assesses the ability of the subject to rotate an image mentally and visualize the object in its new orientation. The test consists of 20 items and lasts 10 minutes. In each item, two isometric perspectives are shown of a three-dimensional object, the second view representing a given rotation from the first position. Then a second object is displayed with five alternative rotations from which the student must select the view representing the same rotation made with the first object (Fig. 1). This test demonstrates a high degree of validity and internal consistency, with a Kuder-Richardson coefficient of $KR_{20} = 0.80$ [38], and is one of the least prone to be resolved by analytical strategies rather than purely spatial ones [39]. The test, also voluntary, was taken by 748 students at the beginning of the term and by 538 at the end, of which 523 took both the initial and final test.

2.4 Procedure

2.4.1 Phases of the study

As commented above, during the first few days of the second term of the academic year 2012/13, the students who were enrolled in five courses of Graphic Expression in the majors Civil Engineering, Chemical Engineering, and Industrial Electronic Engineering of the University of Granada were administered the *Purdue Spatial Visualization Test: Rotations* [38] together with the questionnaire of personal information, experiences, hobbies, and skills. The students were not informed of the result of the spatial test.

During the period of classes over the term, the students of these courses were invited to participate in a set of voluntary spatial skills training activities, integrated into the Graphic Expression courses under study. These activities, based on exercises of freehand sketching, were designed with the purpose of combining and optimizing two methodologies that have rendered good results: the one used by S. A. Sorby and her colleagues at the *Michigan Technological University*, which lead to the publication of the workbook "*Introduction to 3D Spatial Visualization*" [40] that contains more than 500 spatial exercises for pencil and paper; and the "mentored sketching" of Mohler and Miller [33], in which the students completed exercises of this type under the direct supervision of the professor. It is important to remark that these activities were voluntary and that, as stated above, the students were not informed of the results of the PSVT:R at the beginning of the term, and therefore their decision to participate in the activities was based solely on their own perception of their spatial skills and on the importance that they placed on these. A total of 207 students participated to a greater or lesser extent in these activities.

At the end of the term, the students again voluntarily took the PSVT:R and afterwards all were provided with a personalized report on their level of spatial skills and their improvement over the term.

2.4.2 Statistical data analysis

With the great volume of information compiled, the aim was to assess the influence of certain factors on four response variables or dependent variables:

1. Results of the PSVT:R at the beginning of the term.
2. Results of the PSVT:R at the end of the term.
3. Absolute improvement in the test results, i.e. the algebraic difference between post-test and pre-test scores.
4. Relative improvement in the test results, i.e. the percentage of absolute improvement in relation to pre-test scores.

As factors, explanatory variables or independent variables were considered to be:

(a) Personal traits: age, gender, hand preference, relation with Engineering and Architecture of the students' parents.
(b) Experiences and hobbies: to have experience in Technical Drawing courses, construction games, video games, sports with a spatial component or sports in general, graphic-design

programs, and mastery of any musical instrument.
(c) Skills (self-evaluation by the student): general intelligence, spatial visualization, problem solving, imagination, mathematics, freehand sketching, computer use, and affinity for music.
(d) Participation in spatial skills training activities.
(e) Prior level of spatial skills (pre-test scores).

The quantitative variables were analysed by the determination of Pearson's linear correlation coefficient. When this correlation existed, minimum-squares adjustment was applied to the equation of the straight line relating the variables used in the study. For the analysis of the qualitative variables (the majority), a one-way ANOVA and the multiple-comparison *post hoc* tests of Scheffe and Games-Howell were used. In the cases in which the ANOVA assumptions were not fulfilled, the Kruskal-Wallis test was used. In all cases, the confidence level was set at 95% ($p < 0.05$).

3. Results

Tables 1 to 8 present the results of the correlation study between the different factors analysed and the PSVT:R scores at the beginning and end of the term, as well as the absolute and relative improvements between the two tests.

In terms of personal traits (Tables 1 and 2), a certain correlation was found ($p < 0.05$) between age and the post-test scores and with the absolute differences, but not with the pre-test scores nor with the relative differences. Given that all the students were adults, they were not appreciably affected by the development of the spatial abilities proposed by Piaget [16]. Regarding the post-test results, it appears that the spatial skills measured with the PSVT:R slightly decreased with age. Furthermore, gender proved to be clearly related to the test results ($p < 0.001$). In the initial test, the mean score of the males surpassed that of the females by 19.1% and by 11.7% in the final test.

Table 1. Relation between certain personal traits and PSVT:R results

Personal traits		**PSVT:R Results**			
		Pre-Test		**Post-Test**	
Age	Results	No significant linear correlation (p > 0.05)		**Significant linear correlation (p < 0.05)** LSA(1): Post-Test score = -0.164×Age + 18.769	
Gender	Levels (sample size)	Male (508)	Female (240)	Male (355)	Female (183)
	Average (st. dev.)	13.99 (3.53)	11.75 (3.51)	16.11 (2.73)	14.42 (3.26)
	Results and significant average differences	**Significant correlation (p < 0.001)** Males outscore females by 2.24 pts. (19.1%)		**Significant correlation (p < 0.001)** Males outscore females by 1.69 pts. (11.7%)	
Hand preference	Levels (sample size)	Right-handed (631)	Left-handed (53)	Right-handed (442)	Left-handed (43)
	Average (st. dev.)	13.33 (3.68)	13.02 (3.26)	15.63 (2.97)	15.47 (3.15)
	Results	No significant correlation (p > 0.05)		No significant correlation (p > 0.05)	
Parents' profession	Levels (sample size) (2)	Related (85)	Not related (419)	Related (62)	Not related (294)
	Average (st. dev.)	13.47 (3.64)	13.64 (3.27)	16.05 (2.73)	15.76 (2.94)
	Results	No significant correlation (p > 0.05)		No significant correlation (p > 0.05)	

(1) Least squares adjustment.
(2) Parents' profession related or not to engineering or architecture.

Table 2. Relation between certain personal traits and PSVT:R gain scores

Personal traits		**PSVT:R Gain scores**			
		Absolute difference		**Relative percentage difference**	
Age	Results	**Significant linear correlation (p < 0.05)** LSA(1): Abs. Difference = -0.178×Age + 5.776		No significant linear correlation (p > 0.05)	
Gender	Levels (sample size)	Male (331)	Female (180)	Male (331)	Female (180)
	Average (st. dev.)	2,16 (2,69)	2,64 (3,31)	23,51% (61,72)	31,50% (43,18)
	Results	No significant correlation (p > 0.05)		No significant correlation (p > 0.05)	
Hand preference	Levels (sample size)	Right-handed (429)	Left-handed (42)	Right-handed (429)	Left-handed (42)
	Average (st. dev.)	2,34 (2,88)	2,07 (3,40)	24,81% (35,71)	22,21% (41,26)
	Results	No significant correlation (p > 0.05)		No significant correlation (p > 0.05)	
Parents' profession	Levels (sample size) (2)	Related (62)	Not related (284)	Related (62)	Not related (284)
	Average (st. dev.)	2,44 (3,19)	2,36 (2,95)	25,12% (40,06)	24,11% (34,39)
	Results	No significant correlation (p > 0.05)		No significant correlation (p > 0.05)	

(1) Least squares adjustment.
(2) Parents' profession related or not to engineering or architecture.

On the contrary, hand preference and the relationship of the parents to Engineering or Architecture did not appear to influence the test scores ($p > 0.05$).

In relation to experiences and hobbies (Tables 3 and 4), prior experience in courses of Technical Drawing exerted a highly significant influence ($p < 0.001$) in the pre-test scores, such that on average those who had experience outscored the others by some 15.0%. These differences diminished in the post-test scores ($p < 0.05$), since at the end of the term all students had experience in Technical Drawing. Construction games also had a significant effect ($p < 0.001$), as those having used such games with medium to high frequency during infancy scored 15.1% higher on the initial test and 8.6% higher on the final test with respect to those who had used such games with low frequency or not at all. Video games exerted a similar influence ($p < 0.001$), registering differences of 8.0% and 7.8% for the initial and final tests, respectively. Sports practice appeared to significantly affect performance ($p < 0.05$), though moderately on both tests, given the differences of 4% to 6% between those that practiced sports with medium to high frequency and those who practiced sports with low frequency or not at all. Mastery with any musical instrument showed a clear correlation ($p < 0.05$) with the pre-test scores, with a difference of 5.3% in favour of those who had medium or high mastery, but no difference appeared in the final test. Finally, experience with computer applications of graphic design did not appear to alter the test scores ($p > 0.05$).

In the section on skills (Tables 5 and 6), according to the self-evaluations by the students, a significant correlation appeared between general intelligence and the pre-test scores ($p < 0.001$), registering differences of up to 23.0% between those claiming to have high or very high intelligence and the rest of the levels. This correlation was weaker in the final test ($p < 0.01$). There was a striking correlation between the perception that the students held of their own spatial skills and the test results ($p < 0.001$), giving differences of up to 41.0% in the initial test and 22.7% in the final test. A highly significant correlation was also found with the problem-solving skills ($p < 0.001$), with differences of up to 20.4% and 13.8%, respectively. Also, a certain relation appeared between the results of the tests

Table 3. Relation between experiences and hobbies and PSVT:R results

Experiences and hobbies		PSVT:R Results			
		Pre-Test		Post-Test	
Previous experience in technical drawing	Levels (sample size) (3)	Y (572)	N (124)	Y (422)	N (68)
	Average (st. dev.)	13.63 (3.46)	11.85 (4.15)	15.73 (2.98)	14.85 (3.14)
	Results and significant average differences	**Significant correlation (p < 0.001)** Y outscores N by 1.78 pts. (15.0%)		**Significant correlation (p < 0.05)** Y outscores N by 0.88 pts. (5.9%)	
Construction toys	Levels (sample size) (4)	N-L (396)	M-H (327)	N-L (290)	M-H (217)
	Average (st. dev.)	12.46 (3.64)	14.34 (3.45)	15.03 (3.08)	16.32 (2.79)
	Results and significant average differences	**Significant correlation (p < 0.001)** M-H outscores N-L by 1.88 pts. (15.1%)		**Significant correlation (p < 0.001)** M-H outscores N-L by 1.29 pts. (8.6%)	
Video games	Levels (sample size) (4)	N-L (470)	M-H (253)	N-L (341)	M-H (166)
	Average (st. dev.)	12.95 (3.74)	13.98 (3.45)	15.19 (3.02)	16.38 (2.88)
	Results and significant average differences	**Significant correlation (p < 0.001)** M-H outscores N-L by 1.03 pts. (8.0%)		**Significant correlation (p < 0.001)** M-H outscores N-L by 1.19 pts. (7.8%)	
Sports in general	Levels (sample size) (4)	N-L (269)	M-H (451)	N-L (187)	M-H (318)
	Average (st. dev.)	12.88 (3.80)	13.58 (3.57)	15.19 (2.94)	15.80 (3.05)
	Results and significant average differences	**Significant correlation (p < 0.05)** M-H outscores N-L by 0.70 pts. (5.4%)		**Significant correlation (p < 0.05)** M-H outscores N-L by 0.61 pts. (4.0%)	
Sports involving spatial orientation	Levels (sample size) (4)	N-L (392)	M-H (331)	N-L (277)	M-H (230)
	Average (st. dev.)	12.99 (3.87)	13.69 (3.39)	15.14 (3.19)	16.11 (2.73)
	Results and significant average differences	**Significant correlation (p < 0.05)** M-H outscores N-L by 0.70 pts. (5.4%)		**Significant correlation (p < 0.001)** M-H outscores N-L by 0.97 pts. (6.4%)	
Graphic design software	Levels (sample size) (4)	N-L (653)	M-H (70)	N-L (458)	M-H (49)
	Average (st. dev.)	13.29 (3.65)	13.49 (3.88)	15.53 (3.03)	16.08 (2.94)
	Results	No significant correlation (p > 0.05)		No significant correlation (p > 0.05)	
Musical instruments	Levels (sample size) (5)	N-L (566)	M-H (153)	N-L (403)	M-H (102)
	Average (st. dev.)	13.18 (3.58)	13.88 (3.91)	15.48 (3.02)	16.02 (3.03)
	Results and significant average differences	**Significant correlation (p < 0.05)** M-H outscores N-L by 0.70 pts. (5.3%)		No significant correlation (p > 0.05)	

(3) Y: Yes (do have experience); N: No (do not have experience).
(4) N-L: None or low frequency; M-H: Mid or high frequency.
(5) N-L: None or low mastery; M-H: Mid or high mastery.

Table 4. Relation between experiences and hobbies and PSVT:R gain scores

Experiences and hobbies		**PSVT:R Gain scores**			
		Absolute difference		**Relative percentage difference**	
Previous experience in technical drawing	Levels (sample size) (3)	Y (411)	N (66)	Y (411)	N (66)
	Average (st. dev.)	2,21 (2,85)	2,85 (3,14)	22,04% (32,23)	36,67% (47,14)
	Results and significant average differences	No significant correlation (p > 0.05)		**Significant correlation (p < 0.01)** N outscores Y by 14.63 percentage pts. (66.4%)	
Construction toys	Levels (sample size) (4)	N-L (285)	M-H (208)	N-L (285)	M-H (208)
	Average (st. dev.)	2,49 (2,96)	2,00 (2,87)	27,31% (37,15)	20,24% (34,20)
	Results and significant average differences	No significant correlation (p > 0.05)		**Significant correlation (p < 0.05)** N-L outscores M-H by 7.07 percentage pts. (34.9%)	
Video games	Levels (sample size) (4)	N-L (340)	M-H (153)	N-L (340)	M-H (153)
	Average (st. dev.)	2,24 (2,98)	2,39 (2,80)	25,10% (37,90)	22,60% (31,68)
	Results	No significant correlation (p > 0.05)		No significant correlation (p > 0.05)	
Sports in general	Levels (sample size) (4)	N-L (183)	M-H (308)	N-L (183)	M-H (308)
	Average (st. dev.)	2,52 (3,00)	2,15 (2,89)	28,51% (39,50)	21,87% (33,80)
	Results and significant average differences	No significant correlation (p > 0.05)		**Significant correlation (p < 0.05)** N-L outscores M-H by 6.64 percentage pts. (30.4%)	
Sports involving spatial orientation	Levels (sample size) (4)	N-L (269)	M-H (224)	N-L (269)	M-H (224)
	Average (st. dev.)	2,35 (2,94)	2,21 (2,91)	26,67% (39,17)	21,52% (31,82)
	Results	No significant correlation (p > 0.05)		No significant correlation (p > 0.05)	
Graphic design software	Levels (sample size) (4)	N-L (444)	M-H (49)	N-L (444)	M-H (49)
	Average (st. dev.)	2,28 (2,93)	2,35 (2,94)	24,24% (35,71)	25,15% (39,61)
	Results	No significant correlation (p > 0.05)		No significant correlation (p > 0.05)	
Musical instruments	Levels (sample size) (5)	N-L (393)	M-H (98)	N-L (393)	M-H (98)
	Average (st. dev.)	2,33 (2,85)	2,05 (3,18)	24,71% (35,75)	21,38% (35,15)
	Results	No significant correlation (p > 0.05)		No significant correlation (p > 0.05)	

(3) Y: Yes (do have experience); N: No (do not have experience).
(4) N-L: None or low frequency; M-H: Mid or high frequency.
(5) N-L: None or low mastery; M-H: Mid or high mastery.

and the freehand sketching skills ($p < 0.01$), with maximum differences of 8.5% and 6.7%. The influence of the ability to use a computer was weak and barely significant, while no relation was found between spatial skills and imagination, mathematical skills, or affinity for music.

On the other hand, there was a strong correlation between the pre-test and post-test scores, the absolute improvements and the relative ones ($p < 0.001$) (Tables 7 and 8). The average improvements, both absolute and relative, proved to be higher the lower the scores were on the initial test. This was reflected indirectly on finding a certain negative correlation between relative improvements and some factors that do prompt differences in the test results. For example, in relation to the factor experience with construction games, which very significantly influenced the test results, those who had never played with such games or only infrequently, achieved relative-improvement scores 35% higher than those who had played with medium or high frequency.

Also, a significant difference was found in the pre-test and post-test scores between students who participated in the training activities and those who did not. As stated above, the students did not know their test results until the end of the term, and therefore their decision to participate or not in the activities was based exclusively on their own perception of their spatial skills and on the importance they placed on these. The students who did not participate in the activities scored an average of 13.82 points on the initial test, i.e. 17.1% higher than the 11.80 points scored by those who did participate in the activities ($p < 0.001$), whereas in the final tests these scores were 15.77 and 15.06 points, respectively, reducing the difference to 4.7% ($p < 0.01$). With the improvements, an inverse correlation resulted: the participants in the activities achieved an absolute improvement of 68.8% higher than did those who did not participate ($p < 0.001$), and a relative improvement of 76.8% higher ($p < 0.01$).

Finally, Table 9 relates the decision to participate or not in the training activities with the student's self-perception concerning his or her level of spatial skills. This shows a strong negative correlation

Table 5. Relation between perception of own abilities and PSVT:R results

Perception of own abilities		PSVT:R Results					
		Pre-Test			Post-Test		
General intelligence	Levels (sample size) (6)	VL-L (17)	M (358)	H-VH (331)	VL-L (10)	M (258)	H-VH (227)
	Average (st. dev.)	11.35 (3.20)	12.86 (3.65)	13.96 (3.65)	14.20 (2.78)	15,22 (3,08)	16,04 (2,93)
	Results and significant average differences	**Significant correlation (p < 0.001)** H-VH outscores: M by 1.10 pts. (8.6%); VL-L by 2.61 pts. (23.0%)			**Significant correlation (p < 0.01)** H-VH outscores M by 0.82 pts. (5.4%)		
Spatial visualization skills	Levels (sample size) (6)	VL-L (126)	M (281)	H-VH (306)	VL-L (84)	M (193)	H-VH (224)
	Average (st. dev.)	10.71 (3.62)	12.55 (3.39)	15.10 (3.04)	13.81 (3.15)	14,75 (3,06)	16,95 (2,30)
	Results and significant average differences	**Significant correlation (p < 0.001)** H-VH outscores: M by 2.55 pts. (20.3%); VL-L by 4.39 pts. (41.0%). M outscores VL-L by 1.84 pts. (17.2%)			**Significant correlation (p < 0.001)** H-VH outscores: M by 2.20 pts. (14.9%); VL-L by 3.14 pts. (22.7%). M outscores VL-L by 0.94 pts. (6.8%)		
Problem-solving skills	Levels (sample size) (6)	VL-L (69)	M (405)	H-VH (238)	VL-L (40)	M (302)	H-VH (158)
	Average (st. dev.)	11.70 (4.08)	13.15 (3.51)	14.09 (3.69)	14.10 (3.35)	15,54 (3,07)	16,04 (2,78)
	Results and significant average differences	**Significant correlation (p < 0.001)** H-VH outscores: M by 0.94 pts. (7.2%); VL-L by 2.39 pts. (20.4%). M outscores VL-L by 1.45 pts. (12.4%)			**Significant correlation (p < 0.001)** H-VH outscores VL-L by 1.94 pts. (13.8%). M outscores VL-L by 1.44 pts. (10.2%)		
Imagination	Levels (sample size) (6)	VL-L (126)	M (226)	H-VH (364)	VL-L (90)	M (165)	H-VH (248)
	Average (st. dev.)	12.75 (3.45)	13.35 (3.89)	13.50 (3.61)	15.19 (3.02)	15,62 (3,26)	15,68 (2,88)
	Results	No significant correlation (p > 0.05)			No significant correlation (p > 0.05)		
Mathematical skills	Levels (sample size) (6)	VL-L (69)	M (319)	H-VH (328)	VL-L (37)	M (225)	H-VH (241)
	Average (st. dev.)	13.10 (3.85)	13.19 (3.85)	13.49 (3.48)	14.73 (3.60)	15,51 (2,95)	15,76 (3,00)
	Results	No significant correlation (p > 0.05)			No significant correlation (p > 0.05)		
Freehand sketching skills	Levels (sample size) (6)	VL-L (279)	M (221)	H-VH (215)	VL-L (191)	M (156)	H-VH (156)
	Average (st. dev.)	12.78 (3.73)	13.50 (3.60)	13.87 (3.57)	15.07 (2.93)	15,68 (2,98)	16,08 (3,12)
	Results and significant average differences	**Significant correlation (p < 0.01)** H-VH outscores VL-L by 1.09 pts. (8.5%)			**Significant correlation (p < 0.01)** H-VH outscores VL-L by 1.01 pts. (6.7%)		
Computer use skills	Levels (sample size) (6)	VL-L (101)	M (257)	H-VH (357)	VL-L (78)	M (180)	H-VH (244)
	Average (st. dev.)	13.29 (3.54)	12.76 (3.77)	13.73 (3.61)	15.60 (3.08)	15,23 (3,10)	15,80 (2,96)
	Results and significant average differences	**Significant correlation (p < 0.01)** VH-H outscores M by 0.97 pts. (7.6%)			No significant correlation (p > 0.05)		
Affinity for music	Levels (sample size) (6)	VL-L (46)	M (143)	H-VH (519)	VL-L (28)	M (104)	H-VH (364)
	Average (st. dev.)	13.70 (3.08)	13.28 (3.60)	13.32 (3.73)	15.36 (3.26)	15,60 (2,76)	15,62 (3,08)
	Results	No significant correlation (p > 0.05)			No significant correlation (p > 0.05)		

(6) VL-L: Very low-low; M: Medium; H-VH: High-very high (ability or affinity).

between the two factors ($p < 0.001$), indicating that the lower the self-estimation of spatial skills, the more likely was the student to participate in the training activities, and vice versa.

4. Discussion

This study presents some limitations that have to be considered for a proper interpretation of the results of the statistical data analysis:

(a) First of all, it should be remarked that the scope of the present study is correlational, not causal. That is, the aim is to identify the factors that are statistically related to the spatial skills of the students, without seeking to identify the causes explaining the relation.

(b) The main limitations of this study derive from the tools used to collect the information. With the questionnaire of personal traits, experiences, hobbies, and abilities, the student was requested to evaluate certain factors without being told defined criteria with which to do so and thus a certain degree of subjectivity was expected (except for factors such as age, gender, or hand preference). Therefore, caution should be exercised in interpreting the strength of the correlations resulting from the statistical analysis.

(c) Finally, the PSVT:R test also implies a certain limitation in the study since it is not capable of evaluating levels of spatial skills above their maximum score, 20 points. In fact, 23 students scored the maximum on the initial test (3.1%), 36 on the final test (6.7%) and 12 both on the initial as well as the final tests (2.3% of those who took both tests). This means a certain undervaluation both in the mean values of

Table 6. Relation between perception of own abilities and PSVT:R gain scores

Perception of own abilities		PSVT:R Gain scores					
		Absolute difference			Relative percentage difference		
General intelligence	Levels (sample size) (6)	VL-L (10)	M (257)	H-VH (214)	VL-L (10)	M (257)	H-VH (214)
	Average (st. dev.)	3,4 (1,78)	2,30 (3,00)	2,18 (2,91)	35,90%	24,77%	23,14%
	Results	No significant correlation (p > 0.05)			No significant correlation (p > 0.05)		
Spatial visualization skills	Levels (sample size) (6)	VL-L (84)	M (191)	H-VH (212)	VL-L (84)	M (191)	H-VH (212)
	Average (st. dev.)	2,64 (3,45)	2,57 (2,97)	1,88 (2,63)	36,26%	28,46%	15,85%
	Results and significant average differences	**Significant correlation (p < 0.05)** M outscores H-VH by 0.69 pts. (36.7%)			**Significant correlation (p < 0.001)** VL-L outscores H-VH by 20.41 percentage pts. (128.8%). M outscores H-VH by 12.61 percentage pts. (79.6%)		
Problem-solving skills	Levels (sample size) (6)	VL-L (40)	M (294)	H-VH (152)	VL-L (40)	M (294)	H-VH (152)
	Average (st. dev.)	2,75 (2,99)	2,38 (3,01)	1,95 (2,75)	37,28%	24,57%	20,28%
	Results and significant average differences	No significant correlation (p > 0.05)			**Significant correlation (p < 0.05)** VL-L outscores H-VH by 17.00 percentage pts. (83.8%)		
Imagination	Levels (sample size) (6)	VL-L (88)	M (159)	H-VH (242)	VL-L (88)	M (159)	H-VH (242)
	Average (st. dev.)	2,57 (2,73)	2,18 (2,93)	2,24 (3,00)	27,63%	23,95%	23,27%
	Results	No significant correlation (p > 0.05)			No significant correlation (p > 0.05)		
Mathematical skills	Levels (sample size) (6)	VL-L (37)	M (219)	H-VH (233)	VL-L (37)	M (219)	H-VH (233)
	Average (st. dev.)	2,11 (2,88)	2,37 (3,12)	2,22 (2,76)	21,40%	26,63%	22,52%
	Results	No significant correlation (p > 0.05)			No significant correlation (p > 0.05)		
Freehand sketching skills	Levels (sample size) (6)	VL-L (191)	M (148)	H-VH (150)	VL-L (191)	M (148)	H-VH (150)
	Average (st. dev.)	2,22 (3,00)	2,22 (2,80)	2,41 (2,97)	26,01%	23,29%	23,04%
	Results	No significant correlation (p > 0.05)			No significant correlation (p > 0.05)		
Computer use skills	Levels (sample size) (6)	VL-L (77)	M (179)	H-VH (232)	VL-L (77)	M (179)	H-VH (232)
	Average (st. dev.)	2,38 (2,74)	2,37 (3,18)	2,18 (2,80)	24,10%	27,23%	22,07%
	Results	No significant correlation (p > 0.05)			No significant correlation (p > 0.05)		
Affinity for music	Levels (sample size) (6)	VL-L (28)	M (101)	H-VH (354)	VL-L (28)	M (101)	H-VH (354)
	Average (st. dev.)	1,64 (2,38)	2,51 (2,90)	2,27 (2,96)	13,36%	27,15%	24,32%
	Results	No significant correlation (p > 0.05)			No significant correlation (p > 0.05)		

(6) VL-L: Very low-low; M: Medium; H-VH: High-very high (ability or affinity).

Table 7. Influence of the participation in spatial skills training activities on the PSVT:R results

Factors		PSVT:R Results			
		Pre-Test		Post-Test	
PSVT:R Pre-Test scores	Results			**Significant linear correlation (p < 0.001)** LSA (1): Post-Test score = 8.551 + 0.526×Pre-Test score	
Participation in spatial skills training activities	Levels (sample size)	Non-participants	Participants (203)	Non-participants	Participants (179)
	Average (st. dev.)	13,82 (3,35)	11.80 (4.09)	15.77 (2.75)	15.06 (3.46)
	Results and significant average differences	**Significant correlation (p < 0,001)** Non-participants outscore participants by 2,02 pts. (17,1%)		**Significant correlation (p < 0.01)** Non-participants outscore participants by 0.71 pts. (4.7%)	

(1) Least squares adjustment.

spatial skills as well as the improvements achieved over the term.

Thus, in agreement with the results of the statistical data analysis, the factors that appear to be most closely related to spatial skills, measured with the *Purdue Spatial Visualization Test: Rotations (PSVT:R)* [38] at the beginning of the term, and therefore before influencing these specific training activities or the Graphic Expression courses themselves taken by the students during the term, were the following (arranged in descending order of influence):

1st. General intelligence (Fig. 2): the students that claimed to have high or very high intelligence outscored those claiming to have low intelligence by an average of 23.0% (p < 0.001).

Table 8. Influence of the participation in spatial skills training activities on the PSVT:R gain scores

Factors		PSVT:R Gain scores			
		Absolute difference		Relative percentage difference	
PSVT:R Pre-Test scores	Results	**Significant linear correlation (p < 0.001)** LSA (1): Absolute Difference = 8.651 – 0.476×Pre-Test score		**Significant linear correlation (p < 0.001)** LSA (1): Relative Percentage Difference = 140.335 – 8.590×Pre-Test score	
Participation in spatial skills training activities	Levels (sample size)	Non-participants	Participants (175)	Non-participants	Participants (175)
	Average (st. dev.)	1,89 (2,83)	3,19 (2,92)	20,84% (60,93)	36,85% (43,21)
	Results and significant average differences	**Significant correlation (p < 0.001)** Participants outscore non-participants by 1.30 pts. (68.8%)		**Significant correlation (p < 0.01)** Participants outscore non-participants by 16.01 percentage pts. (76.8%)	

(1) Least squares adjustment.

Table 9. Influence of the self-perception of own spatial visualization skills on the decision on whether to participate in the training activities

	Self-perceived level of own spatial visualization skills		
	Very low - low	**Medium**	**High - very high**
Total number of students	126	282	307
Students participating in the activities	54 (42.9%)	81 (28,7%)	59 (19,2%)
Results and significant average differences	**Significant correlation (p < 0.001)** VL-L outscores: M by 14.2 percentage pts. (49.5%); H-VH by 23.7 percentage pts. (123.4%). M outscores H-VH by 9.5 percentage pts. (49.5%)		

2nd. Problem-solving ability (Fig. 3): those with a high or very high capacity scored on average 20.4% higher than did those with low or very low capacity (p < 0.001).

3rd. Gender (Fig. 4): males outscored females by an average of 19.1% (p < 0.001).

4th. Experience with construction games (Fig. 5): those who played such games with medium or high frequency in their infancy scored an average of 15.1% higher than did those who played with less frequency or not at all (p < 0.001).

5th. Prior experience in Technical Drawing (Fig. 6): those who had taken some course of this type outscored those who had not by an average of 15.0% (p < 0.001).

6th. Freehand sketching skills (Fig. 7): those claiming to have high or very high ability scored an average of 8.5% higher than did those with a low or very low ability (p < 0.01).

7th. Video games (Fig. 8): those who had used these types of games with medium or high frequency outscored those who claimed to

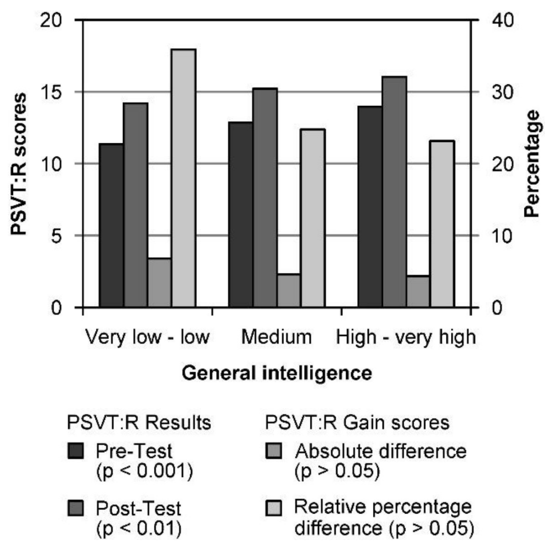

Fig. 2. Relation between general intelligence and PSVT:R results.

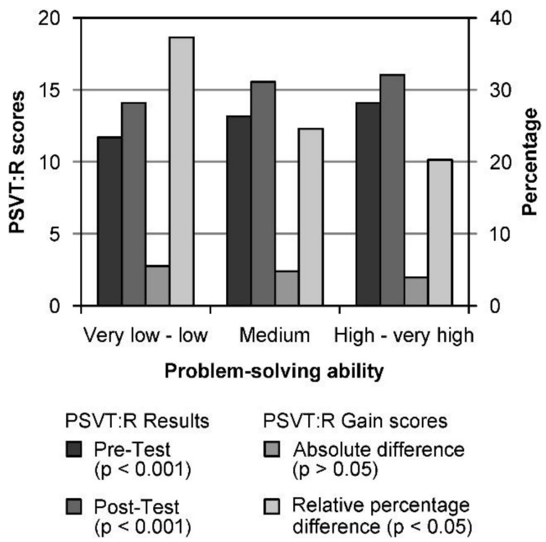

Fig. 3. Relation between problem-solving ability and PSVT:R results.

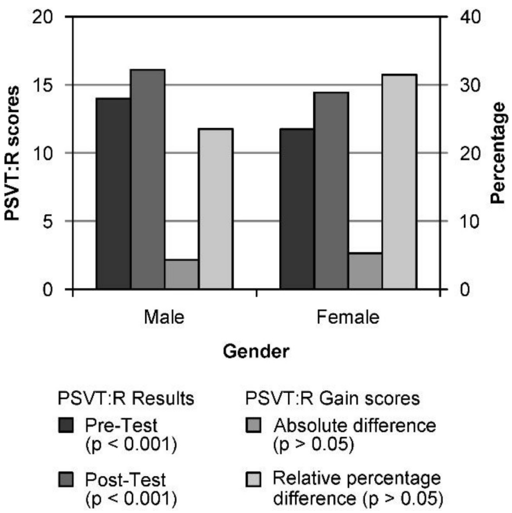

Fig. 4. Relation between gender and PSVT:R results.

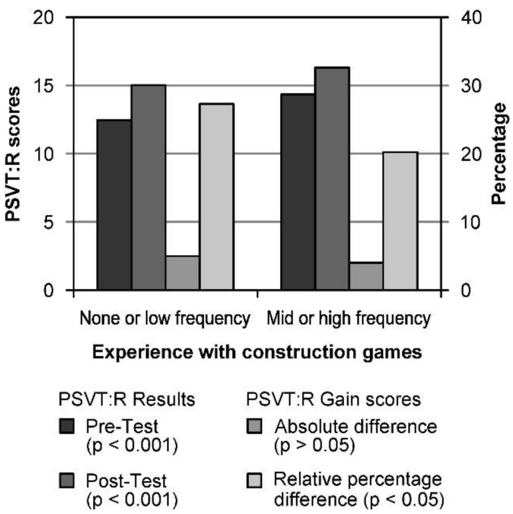

Fig. 5. Relation between experience with construction games and PSVT:R results.

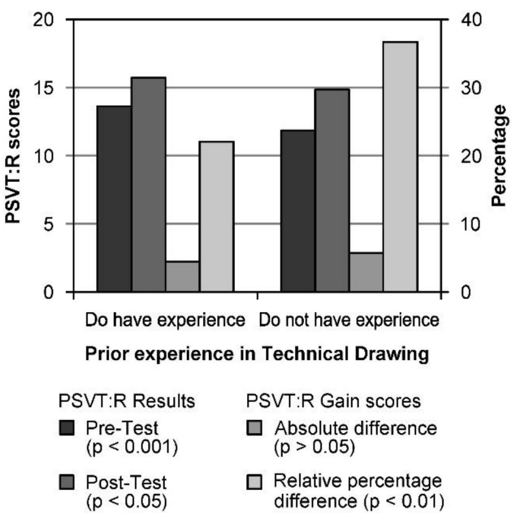

Fig. 6. Relation between prior experience in Technical Drawing and PSVT:R results.

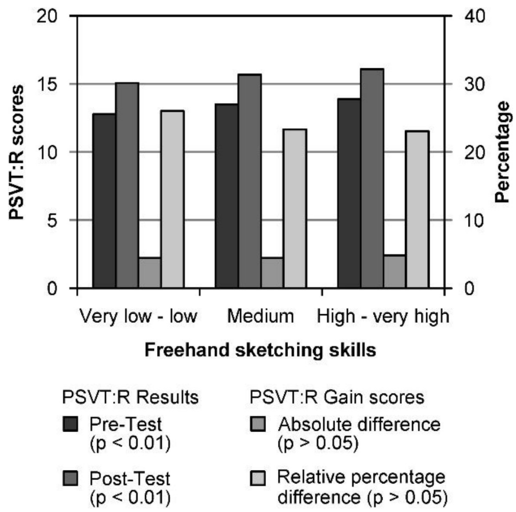

Fig. 7. Relation between freehand sketching skills and PSVT:R results.

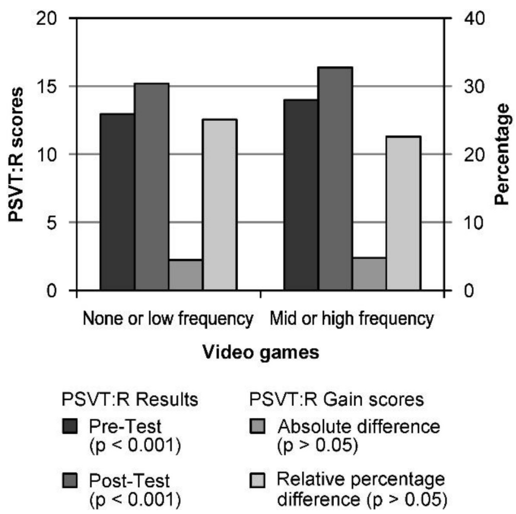

Fig. 8. Relation between experience with video games and PSVT:R results.

have played with low frequency or not at all by 8.0% ($p < 0.001$).

8th. Sports in general and sports with a spatial component (Figs. 9 and 10): those who practiced these types of sports with medium or high frequency scored an average of 5.4% higher than did those who practiced such sports with low frequency or not at all ($p < 0.05$).

The following factors appeared to exert a certain influence on spatial abilities, although with low significance:

- Age: a certain correlation with the results of the final test was found ($p < 0.05$), but not with the initial test.
- Mastery of some musical instrument: although the initial test gave an average difference of 5.3%

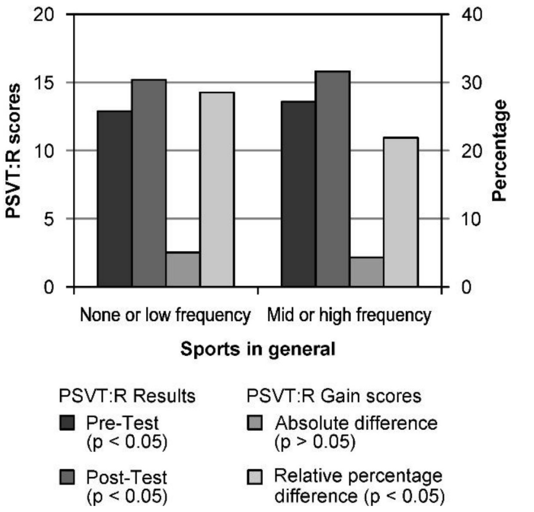

Fig. 9. Relation between the practice of sports in general and PSVT:R results.

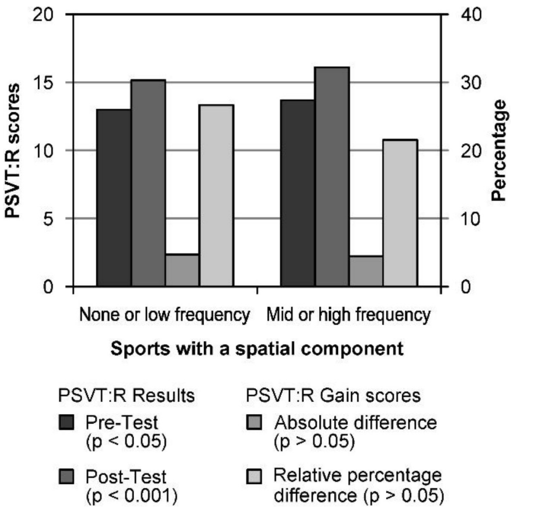

Fig. 10. Relation between the practice of sports with a spatial component and PSVT:R results.

($p < 0.05$) in favour of those who had medium or high mastery, no significant difference was found in the final test.
- Ability to use a computer: in the initial test, a difference of 7.6% appeared ($p < 0.01$) in favour of those with high or very high skills, but this difference did not appear in the final test.

Also, the factors for which no indications of influence on the test results were found are:

- Hand preference.
- Profession of the students' parents in relation to Engineering or Architecture.
- Use of graphic-design programs.
- Imagination.
- Mathematical skills.
- Affinity for music.

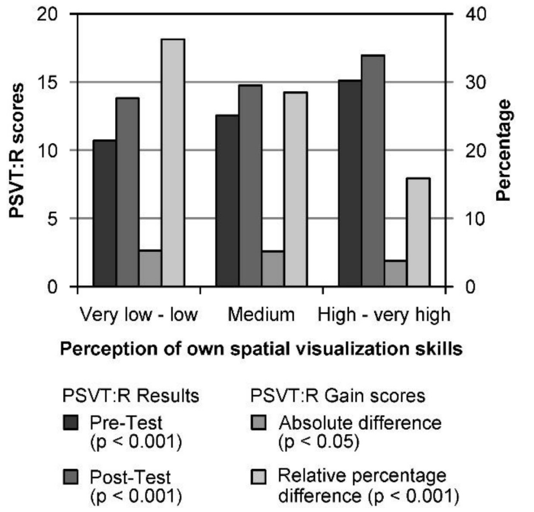

Fig. 11. Relation between the perception of own spatial visualization skills and PSVT:R results.

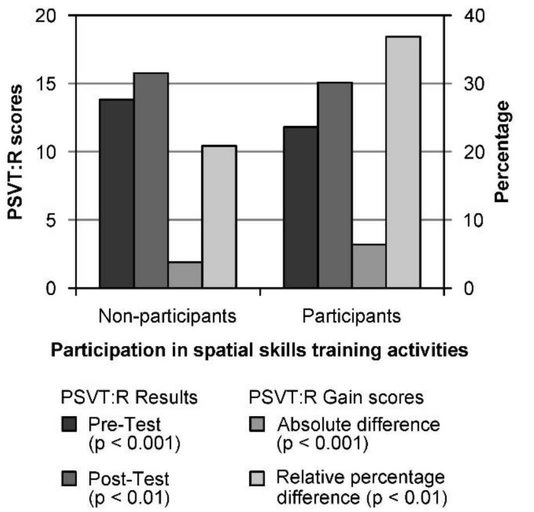

Fig. 12. Relation between the participation in spatial skills training activities and PSVT:R results.

On the other hand, the results clearly indicate that the perception that a student had of his or her own spatial abilities proved to be closely related to the results on the spatial test ($p < 0.001$) (Fig. 11), registering average differences of up to 41.0% between those who considered their own spatial abilities to be high or very high and those who considered their abilities to be low or very low. Furthermore, these latter students constituted the group that most participated in the training activities, with a percentage of 42.9% as opposed to those who considered their abilities to be average (28.7%) and high or very high (19.2%). Therefore, the students appeared to be capable of evaluating their own spatial skills and determining whether they needed specific training.

In terms of the spatial skills training activities designed for the study, the results reflect a high degree of effectiveness, since those that participated in them to a greater or lesser degree achieved an average absolute improvement 68.8% higher ($p < 0.001$) than did those who did not participate, and a relative improvement that averaged 76.8% higher ($p < 0.01$) (Fig. 12). Moreover, the effectiveness was greater the lower the student's prior level of spatial skills. This implies that it is possible not only to train spatial skills but furthermore slight training can result in very significant improvements.

5. Conclusions

It is universally accepted that spatial skills are vital not only for Engineers and Architects, but also for a great variety of fields of knowledge at all levels of the educational system. The present large-scale and in-depth study has identified the personal traits and experiences that most appear to influence these skills. Some of these cannot be acted upon, as in the case of gender (although it remains to be investigated whether it is possible to act on the causes of gender differences in spatial abilities) or general intelligence. However, the other factors for which an influence has been demonstrated (problem-solving skills, playing with construction games, taking Technical Drawing classes, freehand sketching, playing video games, and playing sports) are feasible to integrate in some way into study plans with the aim of ensuring the proper development of the student's spatial skills at each stage of the educational system.

In this sense, some general educational activities should be conducted from childhood according to three lines of action: activities to enhance creativity and critical thinking as means to develop problem-solving skills; plastic arts activities consisting in constructing and manipulating three-dimensional models and in freehand drawing; and activities that require individuals to manage in three-dimensional environments, whether real through sports practice or virtual by means of specific video games.

Furthermore, it is essential for prospective Engineering and Architecture students to take a Technical Drawing course in high school, with particular focus on the classical problems consisting of drawing objects in perspective from a set of standardized views, or vice versa, and on freehand sketching. And in the university stage, a set of spatial skills training activities similar to those designed for the present study should be available for those first year Engineering and Architecture students who did not take classes in Technical Drawing in high school, and in general for those who need to improve their spatial skills. These training activities, which with slight adaptations could be used by students of very different ages and fields of knowledge, consist of solving spatial problems by freehand drawings using the basic notions of Technical Drawing, and have provided very good results, especially in students with low initial level of spatial skills.

References

1. S. A. Sorby, Developing 3D spatial skills for engineering students, *Australasian Journal of Engineering Education*, **13**(1), pp. 1–11, 2007.
2. I. M. Smith, *Spatial ability: its educational and social significance*, London: University of London Press, 1964.
3. R. Arnheim, *Visual thinking*, Berkeley: University of California Press, 1969.
4. R. Arnheim, A plea for visual thinking, in *New essays on the psychology of art*, Berkeley, CA: University of California Press, 1986, pp. 135–152.
5. M. Contero, P. Company, J. L. Saorín and F. Naya, Learning support tools for developing spatial abilities in engineering design, *The International Journal of Engineering Education*, **22**(3), pp. 470–477, 2006.
6. E. S. Ferguson, *Engineering and the mind's eye*, Cambridge, Massachusetts: MIT Press, 1992.
7. J. H. Mathewson, Visual-spatial thinking: An aspect of science overlooked by educators, *Science Education*, **83**(1), pp. 33–54, Jan. 1999.
8. R. Sommer, *The mind's eye: Imagery in everyday life*, New York: Delacorte Press, 1978.
9. J. M. McArthur and K. L. Wellner, Reexamining spatial ability within a Piagetian framework, *Journal of Research in Science Teaching*, **33**(10), 1996, pp. 1065–1082.
10. M. H. Pleck, M. B. Mcgrath, G. R. Bertoline, D. H. Browers and M. A. Sadowski, Factors affecting the engineering design graphics curriculum: Past, present, future, in *Proceedings of the NSF Symposium on Modernization of the Engineering Design Graphics Curriculum*, Austin, Texas, 1990, pp. 43–52.
11. S. A. Sorby, Developing 3-D spatial visualization skills, *Engineering Design Graphics Journal*, **63**(2), 1999, pp. 21–32.
12. K. F. Cochran and G. H. Wheatley, Ability and sex-related differences in cognitive strategies on spatial tasks, *Journal of General Psychology*, **116**(1), 1989, pp. 43–56.
13. C. J. Hamilton, Beyond sex differences in visuo-spatial processing: The impact of gender trait possession, *British Journal of Psychology*, **86**(1), 1995, pp. 1–20.
14. J. L. Pearson and L. R. Ferguson, Gender differences in patterns of spatial ability, environmental cognition, and math and English achievement in late adolescence, *Adolescence*, **24**(94), 1989, pp. 421–431.
15. P. W. Lunneborg, Sex differences in self-assessed, everyday spatial abilities, *Perceptual and Motor Skills*, **55**(1), 1982, pp. 200–202.
16. J. Piaget, *La Representation de l'espacez dans l'enfant*. Paris: Presse Universitaire, 1948.
17. R. Pak, A further examination of the influence of spatial abilities on computer task performance in younger and older adults, *Proceedings of the Human Factors and Ergonomics Society Annual Meeting*, **45**(22), 2001, pp. 1551–1555.
18. M. C. Linn and J. S. Hyde, Gender, mathematics, and science, *Educational Researcher*, **18**(8), 1989, pp. 17–27.
19. C. Riegle-Crumb and B. King, Questioning a White Male Advantage in STEM: Examining Disparities in College Major by Gender and Race/Ethnicity, *Educational Researcher*, **39**(9), 2010, pp. 656–664.
20. M. Eals and I. Silverman, The Hunter-Gatherer theory of spatial sex differences: Proximate factors mediating the female advantage in recall of object arrays, *Ethology and Sociobiology*, **15**(2), pp. 95–105, Mar. 1994.
21. A. C. Medina, H. B. P. Gerson and S. A. Sorby, Identifying gender differences in the 3-D visualization skills of engineering students in Brazil and in the United States, in *Proceedings of the International Conference for Engineering Education 1998*, Rio de Janeiro, Brazil, 1998.
22. D. F. Lohman, Spatially gifted, verbally, inconvenienced, in

Talent development: Proceedings from the 1993 Henry B. and Jocelyn Wallace National Research Symposium on Talent Development, Dayton, 1994, **2**, pp. 251–264.
23. M. P. Michaelides, Age and gender differences in performance on a spatial rotation test. Paper presented at the *Annual Meeting of the American Educational Research Association*, Chicago, IL, 2003.
24. M. Alias, T. R. Black and D. E. Gray, Effect of instructions on spatial visualisation ability in civil engineering students, *International Education Journal*, **3**(1), 2002, pp. 1–12.
25. J. Steele, J. B. James and R. C. Barnett, Learning in a man's world: examining the perceptions of undergraduate women in male-dominated academic areas, *Psychology of Women Quarterly*, **26**(1), 2002, pp. 46–50.
26. M. C. Linn and A. C. Petersen, Emergence and characterization of sex differences in spatial ability: a meta-analysis, *Child Development*, **56**(6), 1985, pp. 1479–1498.
27. J. L. Mohler, Examining the spatial ability phenomenon from the student's perspective, Purdue University, West Lafayette, Indiana, 2006.
28. S. A. Sorby and B. J. Baartmans, A course for the development of 3-D spatial visualization skills, *Engineering Design Graphics Journal*, **60**(1), 1996, pp. 13–20.
29. M. Hassler, N. Birbaumer and A. Feil, Musical talent and visual-spatial abilities: a longitudinal study, *Psychology of Music*, **13**(2), 1985, pp. 99–113.
30. J. Hetland, Learning to make music enhances spatial reasoning, *Journal of Aesthetic Education*, **34**(3–4), 2000, pp. 179–238.
31. T. R. Lord and J. Garrison, Comparing spatial abilities of collegiate athletes in different sports, *Perceptual and Motor Skills*, **86**(3), 1998, pp. 1016–1018.
32. M. Dorval and M. Pepin, Effect of playing a video game on a measure of spatial visualization, *Perceptual and Motor Skills*, **62**(1), 1986, pp. 159–162.
33. J. L. Mohler and C. L. Miller, Improving Spatial Ability with Mentored Sketching, *Engineering Design Graphics Journal*, **72**(1), 2008, pp. 19–27.
34. G. R. Bertoline and E. N. Wiebe, *Fundamentals of graphics communication*, Boston: McGraw-Hill Higher Education, 2007.
35. S. A. Sorby and R. A. Gorska, The effect of various courses and teaching methods on the improvement of spatial ability, in *Eighth International Conference on Engineering Computer Graphics and Descriptive Geometry*, Austin, Texas, 1998, pp. 252–256.
36. R. Hernández, C. Fernández, and P. Baptista, *Metodología de la investigación*, México, D.F.: McGraw-Hill Education, 2014.
37. R. B. Guay, *Purdue Spatial Visualization Tests*, West Lafayette, IN: Purdue Research Foundation, 1977.
38. G. M. Bodner and R. B. Guay, The Purdue Visualization of Rotations Test, *The Chemical Educator*, **2**(4), 1997, pp. 1–17.
39. R. B. Guay, E. D. McDaniel and S. Angelo, Analytic factor confounding spatial ability measurement, presented at the *Annual meeting of the American Psychological Association*, Toronto, Ontario, 1978.
40. S. A. Sorby, A. F. Wysocki and B. J. Baartmans, *Introduction to 3-D spatial visualization: an active approach*. Clifton Park, NY: Thomson, 2003.

Jesús Mataix, PhD is Professor of Engineering Graphics and Geometric Design of Roads and Highways in the Advanced Technical School for Civil Engineering at the University of Granada since 2006. He received the M.Eng. degree in civil engineering from de University of Granada in 1999, and the PhD. degree in engineering from the University of Cordoba in 2014. He performs his professional activity since 1999 at an engineering office, together with the co-author of this paper Dr. Carlos León, holding the posts of Head of the Dept. of Studies and Projects and Quality and Environment Manager. During this period, they have managed more than 240 studies and projects of roads and highways, hydraulic works, structures and urban planning.

Carlos Leon, PhD is Professor of Geodesy and Geomatics and Geometric Design of Roads and Highways in the Advanced Technical School of Civil Engineering at the University of Granada since 2003. He received the M.Eng. degree in civil engineering from de University of Granada in 1999, and the PhD. degree in engineering from the University of Cordoba in 2011. He performs his professional activity since 1999 at an engineering office, together with the co-author of this paper Dr. Jesús Mataix, holding the post of Chief Executive Officer. During this period, they have managed more than 240 studies and projects of roads and highways, hydraulic works, structures and urban planning.

Juan F. Reinoso, PhD is Associated Professor in the Department of Architectural and Engineering Graphic Expression at University of Granada. Dr. Reinoso has been teaching Survey Engineering at University of Jaén (Survey Engineering Degree) and University of Granada (Civil Engineering Master and Architecture Master). His research interest is in Cartographic Generalization and Spatial Data Integration (Digital Elevation Models, Satellite Image Fusion, Photogrammetry and GPS multi traces inference). He has been principal investigator in some projects concerning "Quality Assessment on BIM (Building Information Modeling) applied to cultural heritage" in Spain and "Lidar applied to determination of drainage networks" in USA.