Teaching strategies of architectural representation and design and their relationship with the development of spatial skills in architecture students at Universidad Nacional Federico Villarreal

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Abstract

This study was carried out at the Faculty of Architecture and Urbanism of the Universidad Nacional Federico Villarreal (UNFV) in Lima, Peru, as a doctoral thesis project in education of the Postgraduate University School of the UNFV.
Its objective was to study the relationship between the application of teaching strategies of architectural representation and design and the development of spatial ability in students of that faculty. This is a quasi-experimental study with a control group carried out during the Technical Drawing course of the 2019-1 academic cycle. In the control group, traditional teaching strategies based on the visualization of two-dimensional reduced-scale objects on sheets of paper were applied, while in the experimental group, innovative strategies based on the visualization of real-scale solid objects in three dimensions were applied. The research determined that there is a relationship between the application of teaching strategies and the increase of spatial ability in architecture students and that the greatest increase occurred with the application of strategies based on the visualization of real scale objects in three dimensions. Coinciding with similar research, it was verified that the spatial ability in students can be improved with the training.

Keywords: Architecture, teaching strategies, spatial ability.

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Introduction

Currently, it is considered fundamental for teaching practice not only to guarantee the quality of the educational content but also to establish how it should be transmitted to generate meaningful learning. The first step in the teaching-learning process involves the establishment of a communication link between the students and the teacher, who must facilitate the transmission of information in a fluid and effective way.

Teaching strategies are procedures that teachers use to promote learning among their students. Anijovich & Mora (2009) point out that teaching strategies consist of "general orientations about how to teach a disciplinary content considering what students want them to understand, why and what for". (p.4). This communication process is intentional and directed by the teacher, seeking to produce learning on the part of the students. Intentionality implies that there must be a determined strategy. Pimienta (2012) adds that teaching strategies "are instruments used by the teacher to contribute to the implementation and development of the students' competencies" (p.3).

In educational sciences, competency is a set of capacities, knowledge, skills, and attitudes that human beings apply to learn, adapt and perform in the world (Camargo & Pardo, 2008). The final objective of current education is the development of competencies in the student, even above the transmission of knowledge, which is a necessary but not exclusive element for the construction of an expected competency (Camargo & Pardo, 2008).

In the professional career of architecture, the most important competencies are linked to the understanding and manipulation of space

because the objective of architecture is the definition of habitable spaces for human beings. Architectural design requires the use of spatial ability as an essential aspect of learning and practice since the architect needs to visualize and manipulate space as an idea before doing it in reality. Spatial ability is also related to the development of other skills, such as mathematics (Sorby & Panther, 2020)

Despite the importance of the topic, there is little research in the field of architecture on the development of students' spatial skills and how these can be implemented through the use of appropriate teaching strategies.

Boullosa (2014) points out that the teaching of architectural design in Peru has been guided mainly by the experience and intuition of the teacher. There is neither a theoretical framework nor a definition of clearly established pedagogical procedures. Architecture teachers do not usually have pedagogical training as Dreiffus (2015) points out and use strategies that have been transmitted from teacher to student over the years. On them, each new teacher incorporates his or her characteristics based on his or her personality, experience, and subjectivity. According to Rodríguez (2011), like architectural design, the art of drawing has been transmitted through a teaching-learning process based on the teacher-student relationship, and there are almost no specific and documented pedagogical procedures in this regard.

Architectural teaching strategies have been mainly based on the visualization of reduced scale models in two dimensions (plates) and three dimensions (models). The use of reduced scales has been reinforced with the introduction of computers which, although they allow a better visualization in three dimensions, also limit the total perception of the objects by reducing their format to the size of the screen. Thus, it is not possible to accurately perceive the scale of representation of a design until the graphics are printed in two dimensions (on paper) or three dimensions (through three-dimensional printing).

In this sense, in the search for systematized teaching strategies, we must ask ourselves whether it is convenient to deepen the system of working on the reduced scale or whether it is necessary, especially at the formative levels, to also propose novel strategies based on visualization at real scale in three dimensions that allow students to better develop spatial skills oriented to the particularities of architecture, a discipline based on human dimensions. The case of some branches of engineering is completely different because they work in the design of parts and mechanisms, therefore, the understanding of the real dimension of space and objects is not as important.

One of the researchers who has most addressed the issue of spatial ability in education is Sheryl A. Sorby of Michigan Technological University (MTU). In her recent paper "Is the key to better PISA math scores improving spatial skills?" (Sorby & Panther, 2020) she sought to find a relationship between spatial ability and mathematical ability in school students. The Program for International Student Assessment (PISA) tests are part of a program of the Organization for Economic Cooperation and Development (OECD) that is applied every three years among 15-year-old students from different countries to measure educational quality. The researchers found a correlation between success on the PISA tests, especially in the area of mathematics, and high scores on tests of spatial ability.

Sorby has been studying spatial ability for more than 20 years. In his article "Developing 3-D Spatial Visualization Skills" (Sorby, 1999), he established a theoretical framework for the evolution of concepts and research on the development of spatial ability throughout higher education. He then compared different tests to measure spatial ability among engineering students. One of the tests analyzed was the Purdue Visualization of Rotations Test (PSVT:R), developed at Purdue University by Roland Guay, which measures the ability to perform mental rotations of objects in space. The method used consisted of applying the test in pre- and post-tests, corresponding to the beginning and end of a semester engineering course, and thus evaluating the results of the training received by the students. Sorby (1999) points out that mental rotation is one of the most relevant aspects to determine the level of spatial ability and therefore considers that the Purdue Visualization of Rotations Test (PSVT:R) is a valid tool for its measurement.

Sorby et al. (2013) indicate that there is substantial evidence that spatial skills are an important component of the underlying skills that contribute to student performance in science, technology, engineering, and mathematics, constituting a critical factor for the success of college students in these majors. Research has further determined that spatial ability can be improved with training and the application of appropriate teaching strategies. This is because although the spatial ability is acquired through experience, it can be improved through training.

Throughout his research, Sorby uses the term spatial skill to refer to the acquired skill that can be developed and improved with practice and differentiates it from innate ability. However, the boundary between innate and acquired is blurred, so in the current literature, the terms spatial skill and spatial ability are often used interchangeably.

Spatial ability is directly related to the visual aspects of the development of the human psyche. Allam (2009) indicates that the ability to statically create and dynamically project mental representations of three-dimensional objects in different configurations of space and time is often referred to as spatial visualization. Spatial visualization abilities are the result of genetics (potential), and like Sorby, he concludes that it is not possible to fully determine to what extent the ability to represent and transform space is innate or acquired with practice.

Berkowitz et al. (2021) confirm that students' spatial ability can improve through learning to study architecture, with such improvement appearing early in their studies, but not uniformly.

Although students already develop spatial skills in tasks that are inherent to their career courses, focused training in specific skills can aid the better performance of beginning students, particularly those with initially deficient spatial skills.

Türkmenoğlu et al. (2020) point out that spatial ability is a key factor for jobs such as architecture, where the professional must visualize, transform and scale space. Considering this, they investigated measuring the spatial skills of architecture students in a course of representation techniques. Different tests were applied to the students at the beginning and end of the course, and a significant progression was observed between the tests of spatial visualization-spatial perception and spatial orientation, while no significant progression was observed between the tests of mental rotation and spatial relation-mental rotation. On the other hand, Gómez-Tone (2019) from the Universidad Católica San Pablo del Perú, determined a moderate improvement in the spatial ability of university engineering students in the descriptive geometry course through the use of teaching strategies based on the use of computer models in three dimensions.

Villa (2016) applied the Purdue Visualization of Rotations Test (PSVT:R) before and after the Graphic Expression for Architecture course, where experimental strategies were implemented using computers. At the end of the study, an increase in the level of spatial ability was appreciated, but no definitive result was reached to demonstrate that teaching strategies based on the use of three-dimensional computer models are superior to traditional ones.

Jovanovic & Jones (2014) proposed a teaching strategy to improve students' spatial visualization skills based on the use of real three-dimensional solid models during an academic semester. Psychometric tests, including the Purdue Visualization of Rotations Test (PSVT:R), were used to measure the success of this strategy. The study compared the use of different types of drawing models (a three-dimensional printed solid object, a three-dimensional computer-generated drawing, and a two-dimensional drawing) using a technical drawing activity as the primary assessment tool. It was found that the three-dimensional printed solid model and the three-dimensional computer-generated image provided statistically higher scores than the two-dimensional drawing. Thus, various research concluded that spatial ability can be improved through education.

Currently, in the architecture career, the spatial ability is exercised mainly in design, geometry, and drawing courses. Drawing is the language of the architect, who thinks, reflects, expresses, and communicates (to himself and others) through graphics (Colistra, 2012).

After an idea has been elaborated, it is transmitted through verbal language, but in the case of design, the synthesis of the creative process travels from the receiver to the sender essentially through visual language.

In architectural design courses, communication is also bidirectional, since the teacher must constantly provide feedback on the design process. This communication cannot be produced only verbally, and that is why the development of visual models is necessary. Paz (2000) indicates the following regarding the channels through which this communication takes place:

The medium, as surely suspected, in the case that concerns here are the two-dimensional and three-dimensional bodies as a design response. When building an object, thing, or organism, it contains and carries in its contour, even in its interior, like it or not, a message that conveys both to the maker and the user (p.32)

But architectural graphics not only has the function of transmitting information, but it is also a fundamental tool in the design process because, during the design process, ideas are represented visually and generate feedback of thought.

Given the advances in technology, professional architectural graphics have been rapidly digitized, however, it has not yet been determined how this influences the design process.

Pallasmaa (2012) argues that manual graphics are linked to the elaboration of thought and understanding of three-dimensional space because the hand functions as an extension of the human brain. Therefore, he considers that, despite the advance in digitalization, it is necessary to maintain manual drawing and the manipulation of real objects in the formative stage.

The general objective of this research was therefore to determine the relationship between the use of teaching strategies for architectural representation and design and the development of spatial skills in architecture students at UNFV. The specific objectives were the following:

To determine the level of spatial ability presented by architecture students at UNFV after having applied to them, during an academic semester, teaching strategies of representation and architectural design based on the visualization of reduced scale models in two dimensions and strategies based on the visualization of full-scale models in three dimensions.

To determine whether the spatial ability of UNFV architecture students who received teaching strategies of architectural representation and design based on the visualization of real scale models in three dimensions is greater than the ability of students who received strategies based on the visualization of reduced scale models in two dimensions.

Method

The research is quasi-experimental in that the independent variable X "Teaching strategies of architectural representation and design" is manipulated, but the subjects in the experimental and control groups have not been selected in a completely random way. It is also correlational in that it seeks to determine an association between the two variables studied. The population was constituted by the students of the Faculty of Architecture and Urbanism of the UNFV in 2019, which was 704 people. It was considered to work with two groups: an experimental and a control group. For this purpose, two sections of 2019 students were taken. The sample size was set at 30 students for each group because by the central limit theorem, when the size is 30 or more, the distribution of the average is close to a normal distribution and Student's t-tests can be performed.

The Purdue Spatial Visualization Test: Rotations (PSVT:R), a psychometric test developed in 1976 by Roland Guay at Purdue University, Indiana, was used as an instrument. This test has been extensively tested by researchers around the world in the educational environment to explore spatial ability levels in college students of different majors, such as engineering, architecture, mathematics, and chemistry. The test is freely available as stated by its creator (Bodner & Guay, 1997).

Maeda et al. (2013) perform a review and revision of the PSVT: R, considering that it is a valid tool for the proposed purpose. The PSVT: R shows the drawing of a three-dimensional solid and another image with its appearance after having been rotated a certain number of times. The tested student must interpret how the

rotation has been performed and then apply it on a different solid and choose the correct alternative among five options. Maeda et al. (2013) indicate that the Purdue Spatial Visualization Test: Rotations (PSVT: R) has been recognized as one of the most popular tests for measuring engineering students' ability to spatially visualize mental rotation. This is in part because, compared to other tests, the PSVT: R is unique in that it includes a variety of three-dimensional objects (including objects with tilted, oblique, and/or curved surfaces), and requires a higher level of spatial visualization ability.

The present investigation randomly took two sections of the Technical Drawing course of the Faculty of Architecture and Urbanism of the UNFV. One section was randomly selected as the control group and the other as the experimental group. At the beginning of the academic semester, both groups of students were administered the PSVT:R as a pre-test to measure their initial spatial ability level.

Taking into account the same syllabus for the Technical Drawing course, the same calendar, and the same structure of class sessions, we proceeded to design the application of the teaching strategies to be used per learning session.

During one academic semester, teaching strategies based on the visualization of reduced scale elements in two dimensions were applied to the control group. To the experimental group, teaching strategies based on the visualization of full-scale models in three dimensions were applied. Finally, the PSVT:R was used in a post-test at the end of the course to measure the level of spatial ability after the application of the teaching strategies. Differences between pre- and post-test scores were calculated for both groups and the distributions of these differences were compared. After justifying the normality of the results, a comparison was made employing a Student's t-test for independent means.

Results

The results obtained after the application of the (PSVT:R) were as follows: The scores obtained were categorized into three mutually exclusive levels as follows: If the student did not correctly complete more than half of the 30 items, it was considered a low level (0-15 points), if the student completed 24 or more items correctly, it was considered high (24-30) and in the rest of the cases it was considered a medium level (16-23 points).

In the control group, the number of students with a high level of spatial ability went from 13.3% to 40.0%, while in the experimental group the change in this level increased from 20.0% to 46.7%.

In the case of the experimental group, the average score after the application of the teaching strategies reached a value of 23.60 ±4.20 while in the control group the post average was 20.23 ± 6.95.

Seventy percent of the students who received the teaching strategies based on two-dimensional reduced scale models developed their spatial ability, while in the group with strategies based on three-dimensional real scale models, this percentage was different and higher, reaching 96.7%, i.e. the development is associated with the teaching strategy. Since the Student's t-test indicates that the p-value is less than 0.05, it is concluded at a significance level of 5% that the teaching strategies of architectural representation and design are significantly related to the development of spatial ability.

After teaching strategies were applied to the control group, on average the spatial ability of the students increased from 17.30 to 20.23, the Student's t-test indicates that the observed difference post - pre = 2.93 was significant (p value = 0.010), therefore it is concluded with a significance level of 5% that the spatial ability presented by the students suffered a significant variation after having applied the teaching strategies of architectural representation and design based on the visualization of reduced scale models in two dimensions.

After teaching strategies were applied to the experimental group, on average the spatial ability of the students increased from 17.80 to 23.60, the Student's t-test indicates that the observed difference: post - pre = 5.80 was significant (p value = 0.000); therefore, it is concluded with a significance level of 5% that the spatial ability presented by the students suffered a significant variation after having applied the teaching strategies of architectural

representation and design based on the visualization of real scale models in three dimensions.

The Student's t-test for the two independent samples, control and experimental, indicates that the observed difference (+3.37) between the spatial ability of the students after applying respective teaching strategies was significant (p value = 0.028), in addition to this, if their respective (post-pre) increments are compared, the difference +2.87 is also significant (p value =0.034). Therefore, the spatial ability of students who received teaching strategies of architectural representation and design based on the visualization of full-scale models in three dimensions is higher than the ability of students who received strategies based on the visualization of reduced-scale models in two dimensions.

Discusión

The results obtained have a reliability level of 95% but are limited by the fact that the research will not be extended in the short term in the Faculty of Architecture and Urbanism of the UNFV, so it will not be possible to carry out a longitudinal study to follow up and show the performance of the students evaluated throughout their professional career.

The results obtained agree with those presented by Sorby (1999), Villa (2016), Gómez-Tone (2019), Türkmenoğlu et al. (2020), and Berkowitz et al. (2021) in confirming that spatial ability can be improved through practice and training. It is then valid to ask what are the most appropriate teaching strategies for that purpose.

In the present investigation, it was concluded that the application of real scale models in three dimensions favors the development of spatial ability in students to a greater extent than the use of reduced scale models in two dimensions. This result agrees with that presented by Jovanovic & Jones (2014), who, also employing the Purdue Spatial Visualization Test: Rotations (PSVT: R), determined that the use of three-dimensional printed solid models and computer drawings provides higher scores in the post-test than the use of two-dimensional models. It should be noted that the three-dimensional printed models used by Jovanovic and Jones were of reduced scale, so we cannot compare this point with the results of the present work, where real scale objects were used.

On the other hand, Gómez-Tone (2019) employed three-dimensional models but were exclusively computer-generated. It has not been the aim of the present research to compare strategies based on real objects with those generated by the computer, which opens the field for future research that focuses on this point.

A theoretical contribution is generated by concluding that teaching strategies that use three-dimensional models are more effective than those that use two-dimensional models; however, further research is needed to determine the influence of scales on the development of students' spatial skills and to compare the use of real elements with that of computer-generated elements in three dimensions.

This theoretical contribution can positively influence the practice of teaching architectural representation and design by proposing the use of innovative teaching strategies that contribute to improving the development of spatial ability among students.

Conclusions

It was determined that the use of teaching strategies of architectural representation and design are significantly related to the development of spatial ability in architecture students of the Faculty of Architecture and Urbanism of the UNFV year 2019.

Both the application of strategies based on two-dimensional reduced scale models and strategies based on three-dimensional real scale models meant an increase in the spatial skill level of students in both study groups (control and experimental). This was verified by the application of the Purdue Spatial Visualization Test: Rotations (PSVT:R) in pre- and post-test.

There was an increase in the level of spatial ability in architecture students at UNFV after having applied their teaching strategies of architectural representation and design based on the visualization of reduced scale models in two

dimensions during an academic cycle. The mean difference between the pre-test and post-test scores was 2.93, proving this increase.

There was an increase in the level of spatial ability in architecture students of the UNFV after having applied teaching strategies of architectural representation and design based on the visualization of real scale models in three dimensions during an academic cycle. The mean difference between the pre-test and post-test scores was 5.80, proving this increase.

It was determined that the spatial ability of UNFV architecture students who received teaching strategies of architectural representation and design based on the visualization of real scale models in three dimensions, had a greater increase than the ability of students who received strategies based on the visualization of reduced scale models in two dimensions. The difference between the means between the pre-test and post-test scores in the control and experimental groups was +2.87, proving a significant value after applying the Student's t-test (p value =0.034).

Recommendations

Conduct studies to determine if there is a difference in the development of spatial skills achieved by using architectural representation and design teaching strategies with real models or three-dimensional computer-generated graphics.

To follow up on the architectural representation and design teaching strategies used in drawing and design courses at the next level of the degree program and observe the performance obtained by students in the control and experimental groups.

To propose a longitudinal study on the development of spatial skills involving the architectural drawing and design courses of the following academic cycles.

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