International Journal of Engineering Education Vol. 38, No. 4, pp. 905–916, 2022
Printed in Great Britain
0949-149X/91 $3.00+0.00

Collaborative Graphic Simulation Experience Through Project-Based Learning to Develop Spatial Abilities*

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Engineering and architecture education deals with a great challenge, to develop students' spatial abilities. Although there is an innumerable list of three-dimensional CAD software that seems to overcome this need, the ability to mentally visualize their ideas allows providing solutions faster and in greater detail. At the same time, graphic subjects need to adapt teaching to favor skills such as teamwork and problem solving, while students face how to understand theoretical content that is abstract to them. This research explores a collaborative graphic simulation proposal through Project-Based Learning that responds to the set of needs to determine if the graphic simulation of a real object can improve the spatial skill. The quasi-experimental research involved 29 undergraduate engineering students. The CoGraphS scale was designed and validated to measured student perception towards their involvement in a collaborative graphic simulation and MRT and DAT tests were applied to measure pre and post spatial and mental rotation skills. Descriptive analysis and Student's t statistic were applied to define the sample perception and to verify the improvement of spatial abilities. Multiple linear regression analysis was conducted to examine correlations among PBL variables and students' satisfaction with the process, result, motivation and communication. The results provide evidence of a positive relationship between the experience and the improvement of spatial skills. The manuscript contributes and discusses the influence of a series of variables that have not yet been widely discussed in the PBL in engineering.

Keywords: engineering graphics; spatial abilities; project-based learning

1. Introduction

The spatial ability has gained increasing recognition since the second half of the last century. Numerous investigations support that this capacity is fundamental in many fields, especially in engineering [1], in which the ability to mentally rotate 3D objects is meaningful [2]. These students need to imagine objects in different orientations, to manipulate three-dimensional models, or to mentally reconstruct from two to three-dimensional drawings.

Previous research has correlated good performance in technical degrees with a high level of spatial skills, stating that spatial thinking is essential for scientific thinking. And in addition to its purpose to represent and manipulate information in learning, it is useful for problem-solving [3–6]. This ability may be innately developed, but it has been shown that most people can acquire and improve it through practice [7], especially among students who initially have weak skills [8] and appropriate material [9–11].

Others have evidenced several benefits in the development of both visual ability and mental rotation through different graphic tasks, such as 3D modelling tools [12], 3D tangible models [13] and augmented and virtual reality [14, 15]. Furthermore, spatial abilities have been related to other variables such as creativity and problem-solving competence. Previous research on the design studio performance sought for the relations with creativity and spatial abilities, and among them. They shed light that the discrepancy of results (negative and positive correlations) 'might lie in different thinking structures', referring that their measurement is based on divergent and convergent thinking [16]. Meanwhile, other results evidenced that spatial ability supports the resolution of a large cognitive load imposed on the student in geometry [17]. However, these studies have called for more learning proposals to address this purpose, while there is a need to adapt the teaching methodologies to reinforce the link between education and the labour market.

This manuscript deals with an investigation that relates a project-based learning initiative to improve the spatial capacity of engineering students. The design of the teaching proposal is based on the students choosing the product that they are going to describe and communicate with digital graphic tools.

Engineering graphics is one of the subjects that must develop these skills, but teaching visual lan-

* Accepted 2 January 2022.

guage is a difficult and time-consuming task that requires years. The difficulty of the subject increases due to the low spatial abilities of students who normally do not choose technical drawing in secondary education. This subject is normally based on lectures on the fundamentals of geometry and students must demonstrate its acquisition through individual practice. Students solve these geometric problem practices, but they are not able to relate the theoretical content with its practical application, leading to a loss of interest. At the University of La Laguna, it has been sought to solve these problems of individual approach from the support between peers through groups, in which the tasks require the exchange of information and documentation. Thus, the members of the group ensure that everyone understands the necessary knowledge step by step, leading to a continuous assessment that arises from the method itself and is accompanied by the constant supervision of the professors. The students obtain results that show the usefulness of engineering graphics for their professional future from the analysis and graphic description of an object that interests them. In addition, the division of the project into phases favors that the cognitive workload seems less and they can face it despite the difficulties derived from the low spatial abilities.

In this scenario, project-based learning could be a good answer, because it is based on solving real problems and the student's choice of topic under some requirements criteria checked by the professors: number of pieces (at least 1 per student), modelling difficulty (at least 3 different processes), access to the object for disassembly and measurement and interest of the group as a whole (Fig. 1 displays graphic documentation of the disassembly, measurement and digital modelling process). In addition, it seems sensible that a collaborative nature could contribute to developing a more complex task such as covering a project in the first year of any bachelor degree.

This methodological proposal fits into the engineering graphics curriculum through the collaborative graphic simulation of an engineering product, from sketching and measuring to 3D modelling and animation. And it is based on previous collaborative educational experiences in engineering [18].

2. Background

Spatial skills belong to a group of cognitive functions and skills necessary for the manipulation and processing of spatial information. Specifically, Linn and Petersen [10] defined spatial skills as those that allow us to be able to represent, transform, generate and remember symbolic, not linguistic, information. Lajoie [19] added that spatial skills are necessary to solve tasks that require the manipulation and processing of 3D spatial information.

Since the mid-1990s, different research groups have proposed novel digital tools to improve spatial skills. Sheryl A. Sorby (Michigan Technological University) published a ten-module manual for the improvement of spatial vision that allows working with isometry exercises through block construction, normalized orthogonal views, sections, rotations, etc. Furthermore, this printed book was complemented with digital material based on flash technology [5].

In Spain, the DEHAES research group from the University of La Laguna showed that the use of advanced graphic technologies helps to improve spatial skills. In the first phase, introductory activities dedicated to the modeling of real parts are combined with traditional exercises of engineering graphics in a computer-aided environment. In a second phase, Augmented Reality (AR) technology is applied to combine real elements with virtual elements in the same interface [1]. Case studies that continued with video games and virtual reality [20, 21].

Furthermore, this skill has been correlated with problem-solving [22–24]. This is fundamental when Spain's incorporation into the European Higher

Fig. 1. Processes for graphic simulation of a drone: disassembly, measurement and digital modeling.

Education Area (EHEA) embodied a new scenario that seeks learning based on the acquisition of competencies to focus students on the way engineers work today, which have not yet been fulfilled [25]. At the end of the 20th century, companies indicated that engineers were very individualistic, a profile that did not meet the new needs of the industry: teamwork, managing tasks between various work teams, and shortening design and manufacturing time. Therefore, it has been necessary to prepare the student in what will be her professional life, not only in terms of knowledge, but in the discipline of teamwork. For this, new teaching methods applied to engineering studies such as project-based learning (PBL) have been sought [26].

This collaborative learning methodology in which students acquire an active role favors academic motivation [27, 28] is increasingly common. This approach favors complex problem solving, interdisciplinary communication, collaborative management, and teamwork [29, 30]. In addition, among the wide variety of teaching methodologies, project-based learning stands as one of the most appropriate methodologies for the development of professional engineering competencies [31] since it provides students with autonomy, develops the ability to make decisions and assuming responsibilities through different roles within the work team: the project manager, the 3D modeler, the 2D drawings assistant, the infographic assistant, the video editing manager and the supervisor of additional materials.

Previous research sought to understand the perception of students in a collaborative three-dimensional modeling experience in which these roles were applied. The results obtained indicated a high acceptance of the students towards this type of experiences, who indicated that it helped them to understand how professionals work in collaborative environments [18]. In addition, results have been provided on the effectiveness of collaborative work in Generation Z engineering students, where in addition to obtaining a positive correlation between learning and performance, the students actively participated [32]. At the same time, it is important to keep in mind that teammates do not all start with the same motivation, expectations or self-commitment [33]. This can lead to disappointing learning experiences or, conversely, help those with a more unfavourable starting situation.

Therefore, there is still a need for the development of proposals in engineering graphics that improve spatial skills and promote collaborative work strategies. In addition, this search should complement the transmission of complex contents of the engineering graphics training that can be related to the application in a real case. At this point, Project-Based Learning (PBL) is positioned as an appropriate methodology due to its benefits in improving academic achievement and transferable skills [34] under the basis that students are motivated themselves and make decisions in their learning process [35]. This approach structures the students into small groups that must solve open-ended and real-life problems [36], In this proposal, this premise will consist on graphic representation, digital modeling processes, or complementary proposals such as the use of different technologies (augmented reality, virtual reality, 3D printing, etc.). Likewise, control, communication and self-evaluation processes are essential to understand the learning outcomes in PBL [37]. With the difference between PBL designs becoming increasingly wide, and taking into account the extensive work carried out by Chen, Kolmos and Du [38], the proposal of this research would be problem-oriented PBL at a course level and in a specific field. Previous course level investigations where they applied PBL pointed out similar challenges such as heavy workload and limited time [39, 40].

Considering all the aforementioned that PBL provides meaningful learning experiences which increases student's motivation, problem solving skills, creativity or spatial competences, the following research question arises: How PBL, through a collaborative graphic simulation of a real object, lead to the development of spatial abilities?

3. Methods and Materials

The main goal was to find out whether students' spatial visualization and mental rotation abilities improve based on the collaborative graphic simulation of an object. In addition, project-based learning conditions were analyzed to find out which ones most influence a positive experience. For this purpose, an educational experience was designed and performed at the Universidad de La Laguna with 29 agricultural engineering undergraduate students. And a quasi-experimental research (based on the exploratory approach) was designed to establish a cause-and-effect relationship between an independent variable and a dependent variable, since the use of control groups and random sampling would decrease the sample too much.

The graphic simulation proposal addresses three areas of representation: geographic location, architectural space and product design. The task is carried out by groups that self-manage the tasks depending on their interest. In addition, each member is in charge of one area of the project, although he participates in all of them: project manager, 3D modeler, 2D drawings assistant, infographic assistant, video editing manager and supervisor. Theory sessions will support the viability of the proposal and several software of different nature will be the subject of learning, such as AutoCAD, Revit and Fusion 360.

The spatial visualization and mental rotation of the students was documented before starting the project and once it was completed with the DAT-5SR (Differential Attitude Test) and MRT (Mental Rotation Test) tools. In addition, a 1–5 Likert scale survey on collaborative graphical simulation aspects in PBL was developed and validated.

Mean and standard deviation analyses were performed to describe the sample, while t-student was applied to verify whether there were meaningful differences among pre and post values of spatial abilities. Moreover, Cronbach Alpha is used to assess the internal consistency of the questionnaire and multiple linear regression were accomplished to corroborate which variables influence in the student's satisfaction, motivation and communication in this experience.

3.1 Sample

Convenience sampling was applied due to the exploratory approach of the research, useful to gain a quick understanding of the research fact and to propose future teaching solutions, which is typical in quasi-experimental designs. The target group consisted of 35 undergraduate students in agricultural engineering at University of La Laguna, who enrolled in the 1st year subject entitled Engineering Graphics. A 29/35 ratio completed the course and answered each data collection instrument. Under this sampling consideration, results cannot be generalized but bring findings to debate. In addition, previous studies support similar sample sizes for this type of research. All the students received the test proposal and voluntarily participated, except for some people who did not attend on the days of the test (they were not notified in advance regarding the day or the type of test to avoid possible alterations in the variable to be measured).

3.2 Measurement Instruments

On the one hand, the DAT-SR test belongs to the DAT (Differential Attitude Test) battery, created by George K. Bennet and Alexander G. Wesman. In 1947, Ediciones TEA adapted it under the direction of Mariano Yela. It is used in Spain to measure IQ for many years. A new version called DAT-5 appears in recent years, based on Form C of the 5th American version. There are two forms (1 and 2) that correspond to different levels of difficulty: form 1 is simpler and can be used for the evaluation of subordinates and workers; Form 2 is suitable for evaluating licensed technicians and managers. On the other hand, in 1978 Vanderberg and Kuse were inspired by the work of Shepard and Matzler on mental rotations to create a test called the Mental Rotation Test (M.R.T) [41]. Participants must identify rotated versions of 3D objects composed of cubes. Both, DAT-5 and MRT will be applied to measure visual ability and mental rotation before and after the collaborative graphic simulation experience. These instruments have been widely used in research that measures the spatial abilities of engineering students [7, 15, 42, 43], contrasted and validated in different academic locations and has a version translated into Spanish (used in this research).

Furthermore, the 1–5 Likert Collaborative Graphic Simulation (CoGraphS) perception scale has been designed, in which the minimum value means totally disagree and the maximum totally agree. This data-collection tool will provide results of the students' perception of the collaborative graphic simulation experience to relate to the measurements of spatial abilities. Four professors and researchers from different academic levels participated in the design of CoGraphS, led by a full professor in Engineering Graphics. The content is fundamentally based on the comprehension needs related to graphic media, but from a teamwork and project-based learning approach. These foundations are based on literature, teaching innovation courses for professors at the University of La Laguna and previous research experience on this subject by the authors. It consists of items on graphic digital utilities, formal aspects, collaborative PBL features, engineering project simulation, and control and management utilities (see Table 1).

First, the authors individually compiled the learning peculiarities that the academic proposal would entail over a period of two weeks. Afterwards, they shared the proposals, giving rise to a first common list. The debate led to new contributions, but above all it led to linguistic unification to refer to the same situation. Next, expert judgment was applied thanks to three academics from other Spanish engineering graphics and psychology institutions to assess the reliability. Once the assessments were committed, a pilot test was applied to 15 students from the previous year who had participated in a similar experience to test the alpha coefficient of each item and thus discriminate its statistical validity. This process reduced the items from 25 to 19, which showed robustness and reliability to test the exploratory group. In this manuscript, the CoGraphS alpha coefficient and exploratory factor analysis are calculated on the exploratory group results to confirm reliability and construct validity, respectively.

Table 1. CoGraphS items

Item	**Abbreviate**
Your team members have worked hard	Peer involvement
Assigning roles to group members has led to more efficient work	Role assignment
Fusion 360 is a good application to collaborate	Collaboration
Fusion 360 has favored group communication	Communication
The process of performing the graphic project has satisfied you	GP satisfaction
Group size was adequate	Group size
Immersive realities (AR/VR) are useful to display an engineering project	ARVR utility
Animation is a useful method to display an engineering project	Animation utility
A digital model is useful to display an engineering project	3D utility
The group has used the asynchronous project management environment	A360 utility
The theoretical training helped to be able to solve the project	Theory adequacy
Orthographic projections are useful to display an engineering project	Orthographic projection utility
The web page is a suitable format to expose the graphic project	Web utility
The graphic project method motivates when learning engineering graphics	EG Implication
The graphic project method had encouraged you to get involved in the subject	Subject involvement
Learning Engineering Graphics through a real project is appropriate	PBL learning
Documenting the project development phases is valuable	Documenting
The professors have supported the development of the graphic project	Proff. Support
Synchronous 3D modeling environment favors remote group meetings	E-meetings

3.3 Procedure

The graphic simulation of an engineering project aims to address three main themes: geographical location, the representation of architecture and the graphic documentation of product design.

This is a collaborative proposal that is developed in groups. Students self-manage the distribution of work based on their knowledge and availability of software that they also learn in the subject. For this, each group assigns different roles to the participants: project manager, 3D modeler, 2D drawings assistant, infographic assistant, video editing manager and supervisor of additional materials (models, augmented reality ...). Each role distributes the responsibilities of the project; however, all the members must participate in all the tasks.

In the beginning, each group receives a different cadastral reference that refers to a plot on the island of Tenerife. Students must locate the UTM coordinates and download the digital mapping of the terrain (DGN format) at 1 / 5,000 scale through the IDE Canarias. Each group will incorporate this file into 2D CAD software (AutoCAD) to prepare the location plan and the site plan (see example in Fig. 2).

For the section on the representation of architectural spaces, each group receives the floor plan of a building in jpg format. Students will use BIM (Revit) software to develop their 3D modeling and obtain their views and floor plan (Fig. 3 displays an example of floor plan and axonometric view of the building).

After, each students group had to propose an object to work with, which must fulfil the following

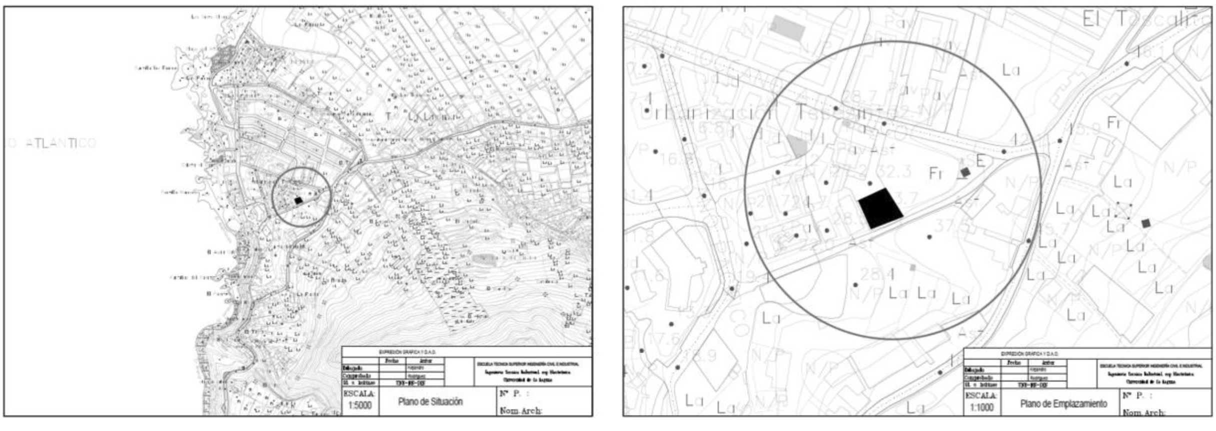

Fig. 2. Location and site plan.

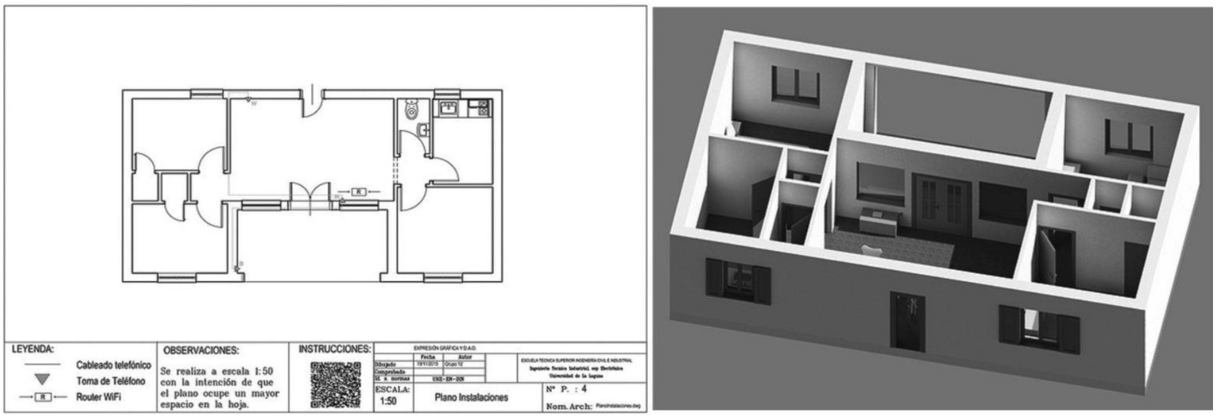

Fig. 3. Floor plan and axonometric view of the building.

characteristics. The object must be composed of at least five different components. The pieces must be simple to model, but for their realization they must use at least 3 different modelling operations (extrusion, revolution, sweep or loft). The pieces must also need editing operations. Each group will model all the parts with a parametric CAD application (Fusion 360) and will obtain the technical documentation (drawings, renders and animation of the assembly). Fig. 4 provides an example regarding sketching, first digital sketches to generate the model and a final render.

Throughout the academic course, students will document the complete graphic simulation process from the first sketches to the development of a final video that will be documented on a web page in order to share the content with other groups. The activity is distributed in twelve sessions (2 hours each).

- Session 1: Students organize themselves in groups of 5 people.
- Session 2: Groups must assign roles, distribute tasks and timing to each member of the group. The professor gives a Wix template to each group to document the development process of the graphic project from the beginning.
- Session 3: The professor gives the geographical reference of the project to each group, as well as the floor plan of the architectural space. Each group must propose an object to the professor, who must accept its viability (i.e. a watch, a PlayStation control, a Wi-Fi router. . .).
- Session 4: The group prepares the location and the site plan of the project.
- Session 5: The group models the building and prints the floor plan.
- Session 6: Once the object to be modeled has been

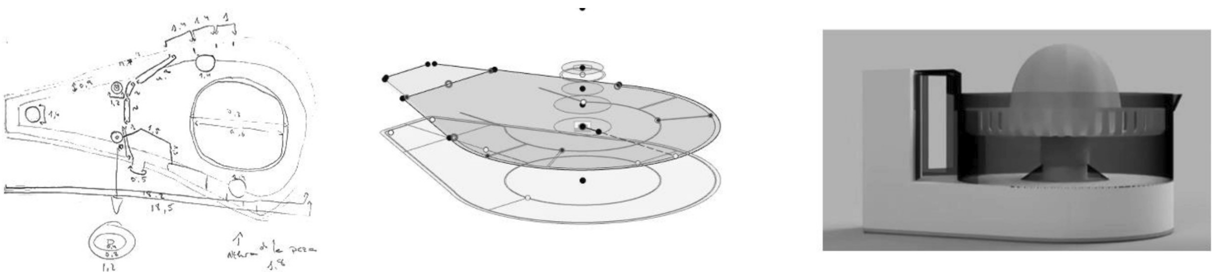

Fig. 4. Orange juicer from sketch to final render.

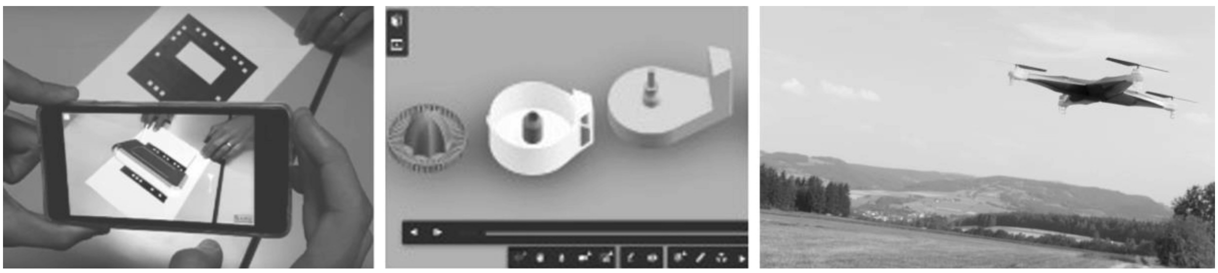

Fig. 5. Additional digital representations: augmented reality (product: a wi-fi router), animation (product: an orange juicer) and rendering through photo-edition (product: a drone).

Table 2. Extraction method: principal component analysis. Varimax rotation method with Kaiser normalization

Factor	Variables	Communalities	Variance explained (%)
1	Peer involvement	0.879	20.68
	Role assignment	0.764	
	Collaboration	0.762	
	Communication	0.721	
	GP satisfaction	0.668	
	Group size	0.661	
2	ARVR utility	0.861	34.581
	Animation utility	0.798	
	3D utility	0.660	
	A360 utility	–0.516	
3	Theory adequacy	0.828	47.089
	Orthographic projection utility	0.740	
	Web utility	0.738	
4	EG Implication	0.860	58.654
	Subject involvement	0.760	
	PBL learning	0.631	
5	Documenting	0.798	68.071
	Proff. support	–0.571	
	E-meetings	0.555	

decided, the students begin the sketch phase and 3D modeling with Fusion 360.

- Sessions 7–11: The group collaborative and simultaneously generate all the graphic documentation.
- Session 12: Finally, each group presents their graphic simulation. Some groups present additional materials such as 3D printed models, renders, online 3D repositories, models in augmented or virtual reality. Some examples are included in Fig. 5.

4. Presentation of Results

4.1 Reliability, Sample Adequacy

Cronbach's alpha was calculated to verify the reliability of the scale, the value obtained (alpha = 0.765) indicates a good level of internal consistency, so the variables are appropriate to measure the perception of the students. Likewise, the sample adequacy has been calculated with the Kaiser-Meyer-Olkin and Bartlett tests (KMO = 0.720; p = <0.001), so the factorial model is pertinent. The factorial structure encompasses five factors that explain the construct in 68 per cent (see variance explained by factors in Table 2): collaborative PBL features (F1), graphic digital utilities (F2), formal aspects (F3), engineering project simulation (F4) and control & management (F5).

4.2 Descriptive Analysis

Mean statistic and standard deviation were applied to describe how students perceived this experience. In general, all the items have evidenced positive results, over 2.90 in a 1–5 Likert scale (see full mean description in Table 3). The highest values pointed out a great acceptation of learning engineering graphics through a real project (m = 4.69) while the collaborative PBL method motivates their learning in this subject (m = 4.41). Furthermore, students designated as extremely relevant the use of animation (m = 4.66) and orthographic projections (m = 4.61) to visualize an engineering project.

Additionally, mean and standard deviation were

Table 3. Descriptive analysis: mean value and standard deviation

Variable	Mean	Std. Deviation
Peer involvement	3.38	1.35
Role assignment	3.10	1.29
Collaboration	3.83	1.31
Communication	2.90	1.35
GP satisfaction	3.59	0.91
Group size	3.48	1.12
ARVR utility	4.34	0.77
Animation utility	4.66	0.55
3D utility	4.31	0.76
A360 utility	3.14	1.77
Theory adequacy	3.86	0.83
Orthographic projection utility	4.61	0.63
Web utility	4.10	1.05
EG Implication	4.41	0.78
Subject involvement	4.28	0.80
PBL learning	4.69	0.66
Documenting	3.76	1.09
Proff. support	4.24	0.87
E-meetings	3.45	1.30

Table 4. Descriptive analysis and Student's t statistic

Variable	Value		Pre-test		Post-test		Sig. t student
	min	max	Mean	Std. deviation	Mean	Std. deviation	
DAT	0	50	24.5517	9.8001	31.6897	9.9071	<0.001
MRT	0	40	16.7586	7.3176	20.9310	8.8233	<0.001
Eng. Graphics interest	1	5	2.8966	1.3957	4.1034	0.8170	<0.001
Process satisfaction	1	5	–	–	3.5862	0.9070	–
Result satisfaction	1	5	–	–	3.8621	1.3017	–
Communication	1	5	–	–	2.8966	1.3455	–
Motivation	1	5	–	–	4.2414	0.7863	–

Table 5. Multiple linear regression results (dependent variable: student satisfaction with the process)

	Adjusted R^2	Std. Error	F	df1	df2	Sig. F
Process satisfaction	0.765	0.444	6.649	1	23	0017
Result satisfaction	0.452	0.889	6.315	1	25	0.019
Motivation	0.438	0.590	4.558	1	24	0.043
Communication	0.582	0.852	5.046	1	23	0.035

applied to DAT, MRT and other variables related to the collaborative PBL experience. Regarding the results in Table 4, both student spatial visualization and mental rotation have increased, with an average value of 6.13 and 4.18 respectively, and the student interest in Engineering Graphics has increased from 2.89 to 4.10. Then, Student's t statistic (paired) was calculated for the three variables, which showed statistical meaningful differences between pre and post results ($p < 0.001$).

Furthermore, student satisfaction of the process and with the result received intermediate values, their motivation in the project received the highest one (m = 4.24) and communication in the collaborative experience of graphic simulation was scored with the lowest result (m = 2.89).

4.3 Multiple Linear Regression Analysis

The multiple linear regression Analysis (MLRA) was applied to examine whether the CoGraphS scale and the spatial skill can predict the student satisfaction with the process and the result, the communication and the motivation (see Table 5).

Regarding the process, student satisfaction has shown to be explained in a 76.5 per cent by the degree to which they are motivated to learn engineering graphics through a PBL, peer involvement, spatial capacity and theory adequacy (see Table 6). Meanwhile, the degree to which they are motivated to learn engineering graphics through a PBL and the perception of utility of drawings explains 45.2 per cent of satisfaction with the result. Motivation has evidenced to be predicted in a 43.8 per cent by the group size, the teacher support and the group communication. In addition, the involvement of colleagues, the perception of usefulness of the AR to communicate the project, the possibility of meeting at a distance and the usefulness of the project management environment (A360) explained 58.2 per cent of communication in the collaborative experience of graphic simulation.

It can be highlighted that the items have better explained the process satisfaction over the other dependent variables, which has direct correlation with the motivation based on the collaborative graphic simulation through the PBL experience, as well as the degree in which it has encouraged to get involved in the Engineering Graphics subject is related with the result satisfaction. Meanwhile, spatial capacity has evidenced an indirect relation with the process satisfaction, meaning that students with less visual skill perceive that the didactic proposal has more benefits than students with greater ability to mental visualize objects.

Also, the comfort within the workgroup have shown to be crucial, since it directly correlates with the process satisfaction and communication, accompanied by the direct relation of group size with student motivation, and the indirect relation of group communication with the motivation. Furthermore, theory adequacy and professor support have shown to be direct related to the process satisfaction and motivation. Finally, regarding output graphics utility, the newest technologies evidenced indirect relation with communication; meanwhile orthographic plans demonstrated a positive one with the result satisfaction.

5. Discussion and Conclusions

In recent decades, specific research has demonstrated that experiences based on digital graphic media, such as computer-aided design, videogames or virtual and augmented reality can enhance spatial skills. How-

Table 6. Multiple linear regression models

Dependent variable	Variable	Beta	t	Sig.
Process satisfaction	(Constant)		1.375	0.182
	EG implication	0.356	3.172	0.004
	Peer involvement	0.522	5.119	<0.001
	Spatial capacity	–0.310	–3.287	0.003
	Theory adequacy	0.268	2.579	0.017
Result satisfaction	(Constant)		–1.824	0.080
	Subject involvement	0.448	2.885	0.008
	Orthographic projection utility	0.390	2.513	0.019
Motivation	(Constant)		2.128	0.044
	Group size	0.705	4.214	<0.001
	Professor support	0.499	3.284	0.003
	Group communication	–0.367	–2.135	0.043
Communication	(Constant)		4.198	<0.001
	Peer involvement	0.633	4.983	<0.001
	AR-VR utility	–0.668	–4.251	<0.001
	E-meetings	0.444	3.110	0.005
	A360 utility	–0.324	–2.246	0.035

ever, the experiences and tasks for this purpose are usually individual in nature, which is far from the most current job demand in engineering. And furthermore, they do not provide solutions to the challenge that all students face in assimilating deep theoretical contents that are the foundations of first-year subjects such as Engineering Graphics. In this research, an initiative that unifies these three needs has been proposed through a collaborative graphic simulation experience through PBL.

The CoGraphS scale was designed and validated to assess students' perception of the collaborative graphic simulation experience, which showed a structure in five factors: collaborative PBL features, graphic digital utilities, formal aspects, engineering project simulation and control & management. This data collection tool made visible that the students' most positive perception of the experience was about their motivation to learn from a real case and the collaborative approach to learning engineering graphics. These findings support previous results that relate this attitude towards the applicability of learning [18].

At the same time, the use of computer aided design, three-dimensional modeling and information management (BIM) software has verified a positive relationship with spatial skill and mental rotation. The results confirm previous research on the use of several digital graphic means to boost these skills [1, 5, 20, 21]. In this proposal, consistency comes from the ease to visualize three-dimensional models using the orbit tool, so students with low spatial abilities are able to complete each task while improving their capacities. However, although the graphic media is a relevant factor, the students' perception of the PBL experience allows us to delve into this relationship [44]. In global terms, the results were positive towards the proposal, which resulted in a good assessment for the collaborative work process, the result of the graphic simulation and the motivation towards the subject. Though, the greatest interest lies in deepening their relationship with the variables of the research.

Regarding collaborative PBL features, communication between teammates was one of the worst-rated variables after the experience, with almost one point less than collaboration. In general terms, collaboration itself entails complications, such as the fact that each student starts from a different cognitive level or attitude towards the project [32]. It is possible both collaboration and communication have some relationship but this study does not provide evidence in this regard. It is noteworthy that the students consider that they collaborate to a good extent, at the same time they identify poor communication, which denotes the lack of knowledge in PBL experiences. In addition, as previous research has pointed out, those who have not had experiences with teamwork and PBL are more likely to find difficulties when dealing with conflicts in collaboration, in the way of communicating effectively or dealing with those colleagues 'opportunists' [45]. However, this proposal has brought to the light a finding about the collaborative approach, which has supported those students with lower levels of spatial ability, since an inverse relationship between spatial skill and process satisfaction of the experience has been confirmed. In addition, peer involvement and e-meetings were positioned as fundamental axes for communication, while the collaborative work management system A360 and the perception of the usefulness of augmented or virtual reality were indirectly related. These results support the lack of project management skills [45, 46], while they focus on solving the objective of each task.

Specifically, process satisfaction has revealed a positive relationship with the PBL method to learn engineering graphics, peer involvement and theory adequacy. The last variable involves the adaptation of theory to the different stages of the project. While it is true that it is not mentioned much in PBL, it is based on student monitoring [47] and dosing in phases for long-term PBL. And above all to reinforce in the case of Engineering Graphics the acquisition of the knowledge of direct application in the following task. In addition, satisfaction of teamwork is essential when it comes to PBL applications to a course, since the duration may affect the effectiveness of PBL especially if they are not used to the PBL methodology [48]. The positive results obtained support the proposals for the application of PBL methods at different levels, establishing guided learning objectives or by stages [38]. Regarding result satisfaction, only a direct relationship was found with the ability of the PBL method to attract the student to the subject and their perception of orthographic projection utility. This result is consistent with the fact that a first-year student visualizes that this projection system is part of the real-life problems [49], so they feel that the learning outcome is suitable and significant.

Furthermore, the results demonstrated that the professor support, the group size and the group communication are fundamental for the correct motivation of the group. The students have expressed a very high level of motivation about the collaborative proposal despite the lack of communication in the group. In addition, teacher support becomes a variable that complements motivation and is related to that continues monitoring and the breakdown of cognitive load into small tasks [17] to avoid discouragement or abandonment of students. On the other hand, group sizes have also been timely in line with PBL experiences of a similar nature in engineering [50, 51].

In addition to the relationships between PBL parameters and their effectiveness in the development of the collaborative graphic simulation experience, or their influence on the development of spatial abilities, a substantial improvement in the engineering graphics interest of students has also been observed. The aforementioned allows to conclude that the graphic collaborative simulation based on project-based learning approach improved student's spatial abilities in this case. The exploratory nature does not allow generalization of the results, but new contributions have been evidenced that complement the current theory in PBL. It is essential to continue the work, so the dissemination and design of proposals to improve teaching in engineering graphics is encouraged.

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