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Exploring Freehand Drawing Skills of Engineering Students as a Support of Visualization

Alfonso Martín Erro [1,*], María Luisa Martínez Muneta [2] and Ángel Antonio Rodríguez Sevillano [3]

[1] Escuela de Arquitectura, Ingeniería y Diseño, Universidad Europea de Madrid, 28670 Madrid, Spain
[2] Escuela Técnica Superior de Ingenieros Industriales, Universidad Politécnica de Madrid, 28040 Madrid, Spain; luisa.mtzmuneta@upm.es
[3] Escuela Técnica Superior de Ingenieria Aeronáutica y del Espacio, Universidad Politécnica de Madrid, 28040 Madrid, Spain; angel.rodriguez.sevillano@upm.es
* Correspondence: alfonso.martin@universidadeuropea.es

Abstract: The importance of having engineering students proficient in visual literacy has long been recognized. Within this objective, the role of freehand drawing is paramount. It is, therefore, important to reinforce its practice for engineering communication and visual thinking support. This paper reports the findings of a research project aimed at studying the visual literacy skills of engineering students and the use of freehand drawing for this purpose. This exploratory study focuses on visualization and its externalization through freehand drawing. An empirical study was conducted with 66 engineering students from the *Universidad Politécnica de Madrid* (Spain). Their skills for expressing visualized images through freehand drawing and their tendency to use drawings for problem-solving were evaluated. The findings of the study indicate that students generally lack skills in expressing ideas through freehand drawing. Additionally, they do not tend to apply drawing when finding solutions to given problems. Considering the importance of freehand drawing to reinforce visual literacy, the implementation of its practice is encouraged in order to have students competent in thinking and communicating through these means.

Keywords: visual literacy; engineering education; visualization; freehand drawing; drawing for problem solving

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1. Introduction

Visual literacy appears as an essential skill set for engineering students of the current century [1,2]. The importance of visual literacy in engineering is well acknowledged [3–7]. Visual literacy refers to the connection between visual communication, learning, and thinking [8–10]. For an engineer, this involves understanding and interpreting drawings and sketches [6], computer models [11] or physical models [12]. It also uses visual imagery to define and find solutions to problems [5]. The need to include visual literacy in engineering curricula has been recognized for decades [1,13]. One of the most important skills in the development of visual literacy is visualization. This is considered essential for engineering education [4]. Interpreting and creating technical drawings requires fully developed spatial visualization skills [14]. Also, as great visual thinkers, engineers tend to use mental imagery in defining and finding solutions to problems [4]. Freehand drawing stands out as the most appropriate resource to help develop visualization skills [15]. It is a fast and effective means of externalizing ideas and actively participating in ideation cycles [16]. Freehand drawing practice is thus understood as a key tool for visualization support and must be considered in that sense in engineering education.

Many scholars recognize freehand drawing practice as of great importance in engineering [6,17], but it is often overlooked in curricula [18–21]. Yang and Cham [22] indicated that sketching training for US engineering students is occasional, as well as Booth [23], who warned that it is treated in many educational institutions as unnecessary and only

taught to emphasize the principles of engineering drawing and computer-aided design. Taborda et al. [24] explained that it is often seen as an obsolete technique, replaced by computer-aided design (CAD). Ullman Wood and Craig [17] noted that most engineers do not receive formal instruction in sketching, assuming that it is a natural skill. Therefore, it can be inferred that the use of drawing by engineers to support thinking depends only on their individual tendency to do so. This predisposition of students to draw for thinking support tasks may be influenced by individual factors. One is their own drawing skills that they acquire by their own talent or practice. The other factor is creativity. There is a relationship between visual thinking and creativity. Creative engineers and scientists were great visual thinkers [5,12]. Therefore, those who show a tendency to externalize ideas or solutions to problems through drawing can be expected to have high creative performance.

The goal of this paper is to report on the use of freehand drawing in the academic environment, as a means for quick externalization as well as to support the ideation process. Our study aims to explore how adept students are at expressing ideas through freehand drawing, as well as to explore how they use drawing as a support to solve problems.

Our contribution consists of providing an updated notion of the competencies of idea externalization in a specific context (the engineering curricula of Spain). This is analyzed in two specific cases. First, we show how engineering students can express themselves by drawing an idea generated in the mind's eye, and second, we review the tendency to use drawings when solving a given problem.

The results are expected to provide guidelines for improving freehand drawing training for complete visual literacy in engineering students.

2. Method

2.1. Participants

Our study is focused on the educational environment in Spain. This study was carried out with a sample of 66 volunteer university students with two engineering programs from the *Universidad Politécnica de Madrid* (UPM) in Spain. These students pertained to two different groups. The first study group (Group 1) was integrated of 32 freshmen (first year) students with the *Escuela Técnica Superior de Ingenieros Industriales* (ETSII) degree in Industrial Engineering. The second study group (Group 2) was made up of 34 undergraduate (fourth year) students with the *Escuela Técnica Superior de Ingenieria Aeronáutica y del Espacio* (ETSIAE) degree in Aerospace Engineering

The sample was selected according to the nonprobability purpose criterion, as intact classrooms. In this case, the criteria applied revolved around the availability of testing in the engineering schools, the differentiation of educational stages (freshmen and undergraduate), and the breadth of the engineering areas (Industrial Engineering and Aerospace Engineering). The characteristics of each group allowed for comparisons of the results, following the criteria of age, academic year, and discipline.

2.2. Materials

2.2.1. Instruments

Three data collection instruments designed for this empirical study were applied:

(1) A preliminary survey to review the perceptions of participating students on their basic background in engineering graphics as well as freehand drawing skills.
(2) A drawing test, to assess the skills to express an idea generated in the mind's eye.
(3) A problem-solving test, to evaluate the tendency to use drawings to solve problems.

The survey consists of a questionnaire intended to discover the notions of the basic knowledge and skills in engineering graphics (EG) of the participants. In this questionnaire, they were asked to declare their level of training in three basic topics of EG subjects: perspective, representation systems (dihedral system), technical drawing standards (e.g., dimensioning, tolerances), as well as computer-aided design. These basic EG topics were identified according to the evaluations of the contents of the EG subjects contents in Spain, as shown in the work of Font Andreu [25], Manchado [26], and Mataix [27]. In addi-

tion, participants were asked to record their perceptions about how skilled they are in drawing freehand.

The drawing test consisted of evaluating the freehand drawing skills of students to express an envisioned idea. Participants were asked to draw a simple mechanism (a bicycle) in as much detail as possible. This empirical test follows criteria from similar work. Manning and Hampshire [28] asked a group of engineering students to draw a bicycle before and after a basic sketching course. Yang [22] conducted a similar drawing test, along with a sketching skills test and a mental visualization expression test. In our case, we aimed to determine to which extent study participants can visualize an object in their mind's eye and express it in a drawing.

The problem-solving test consisted of solving a given problem without any other indication. The aim was to find the tendency of the students to find solutions visually when solving a problem that did not directly involve the use of graphical means, such as a design problem. The statement was to find ways to better balance car and bicycle lanes to help traffic issues and mainly reduce CO_2 emissions.

2.2.2. Evaluation Parameters

Figure 1 shows all the parameters and variables used in this study, the research questions, the variables used, and the instruments for their collection. Three categories of variables were used for this study. First, those related to measuring the graphic skills of the study participants. Second, those related to creative performance. The third category of variables enables the study of how graphics are used for expressing solutions to problems.

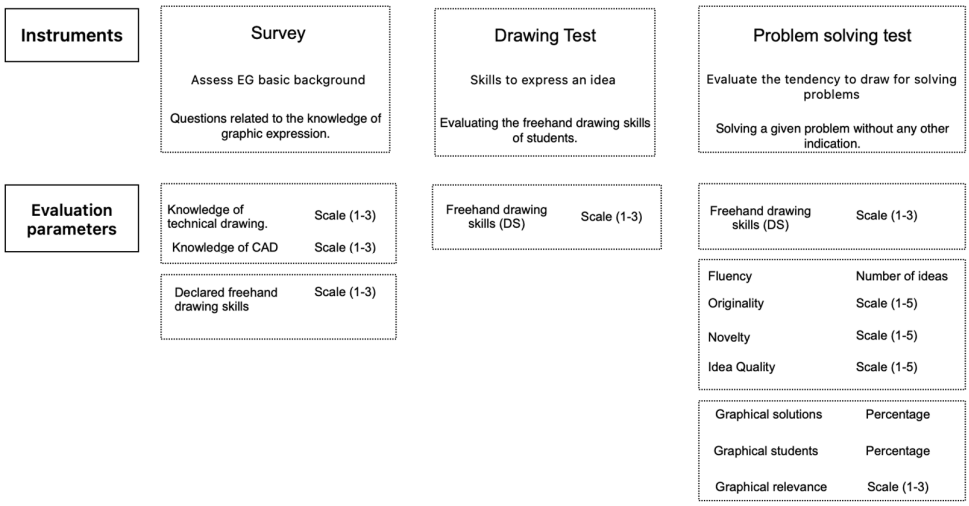


Figure 1. Variables, categories, and instruments used in the study.

Four parameters were used to record how the participating students perceived their competency in EG and freehand drawing: perspective, dihedral system, dimensioning/tolerances/standards, computer-aided design, and declared freehand drawing skills. The measure criterion was a scale, ranging from 1 (Poor), through 2 (Average), to 3 (Good). This scale was chosen because it is equal to the achievement of the three levels of competency assessment (elementary, intermediate, and competent), defined in the European framework of visual literacy competencies, the CEFR-VL [29].

While the declared freehand drawing skills showed how participants feel they are good at drawing, observed freehand drawing skills (DS) empirically evaluate their actual level. DS was defined as the average of two parameters: representation quality (RQ) and sketch quality (SQ):

$$DS = \frac{RQ + SQ}{2} \quad (1)$$

Representation quality (RQ): Based on Booth [23], Kudrowitz [30], and de Vere et al. [18] This parameter consists of the average of ratings from 1 to 3 (1: poor, 2: average, 3: good) of the following factors:

- Use of perspectives/projections.
- Correct proportions. Relative size of the elements.
- Lines. Straight-line execution quality.
- Curves. Performance quality of curved lines.
- Details.
- Size of the drawing. Percentage of drawing with respect to the size of the paper.

Sketch quality (SQ) is defined according to the average of a set of assessments that are annotated by each evaluator for each sketch (1: poor, 2: average, 3: good):

- Bicycle representation (1: bicycle not correctly represented, 2: it seems to look like a bicycle, 3: clearly represents a bicycle).
- Representation of bicycle elements (1–3): Are the main bicycle components included? Are functional details of the bicycle (cables, brake pads) included?
- The sketch clearly expresses how the bicycle works (1–3).

As seen in Table 1, two types of variables were used in the problem-solving test. First, those that measure ideation capacities (fluency, originality, novelty, and idea quality) and second, variables that evaluate the tendency of drawing when solving problems (rate of graphics solutions, rate of students using drawing solutions, resolutive graphic capacity, and graphic relevance).

Table 1. Observed freehand drawing skills.

	Group 1		Group 2		
	Mean	**Standard Deviation**	**Mean**	**Standard Deviation**	***p*-Value**
Sketch Quality	1.125	0.336	1.424	0.561	0.534
Quality of Representation	1.406	0.499	1.848	0.364	0.216
Observed freehand drawing skills (DS)	1.266	0.359	1.636	0.415	0.861

The second category of variables collects the results of the ideation capabilities of participant students. These are fluency, originality, novelty, and idea quality and are used in several works measuring creative performance [31]. Fluency, or the number of ideas generated, is the most objective parameter, as observed by Cardoso [32], and is also stated by Gilford [33] as an element of the creative process. Originality is defined by Cardoso [32] as indicating the unusualness of an idea compared to others or to other similar concepts or solutions, which was also a creative parameter exposed by Guilford [34]. Finke's [35] scale from 1 (not at all original) to 5 (very original) is a subjective evaluation scored by a group of experts. In our case, it was carried out by the research team of this study. When assigning the value on the scale, the frequency of repetition of the solution was considered according to the rest of the participants, so that a 5 would correspond to a solution not repeated, a 4 to a solution repeated 5% of the time, a 3 to 10%, a 2 to 25% and a 1 from 50% onwards.

The novelty of an idea is assessed according to the criteria of Shah [31], who evaluated novelty according to how unusual it is. It is assessed according to similar criteria to originality. The difference between the two is that an idea can be novel if the combination of already-known ideas results in an unusual solution.

The quality of an idea is also a recurring parameter used to measure the creativity of an idea, as, for it to be creative, it must have an application to the given problem. The evaluation was carried out by the research team of this empirical work, also with a scale of 1 to 5. They followed an evaluation methodology like that proposed by Toh [36], consisting

of the sum of five questions valued from 1 to 0, depending on whether they are affirmative or negative, respectively.

- Q1: Does the idea solve the problem?
- Q2: Does the idea not have a negative impact on other factors?
- Q3: Is the idea feasible?
- Q4: Is the idea easy to implement?
- Q5: Does the idea have a minimal economic impact?

Having finally:

$$\text{Idea Quality(IQ)} = \sum_{i=1}^{5} Qi \quad (2)$$

The last category of variables (the rate of graphical solutions, rate of graphical students, and graphical relevance) measures how graphics are used to express solutions, and, therefore, can evaluate the amount of use of drawing for thinking support. These parameters were defined specifically for this research work. The rate of graphical solutions and the rate of graphical students evaluate the graphic tendency for problem solving. The first parameter measured the percentage of whole solutions where any drawing was used. Graphical students also identify the percentage of participants who applied a drawing in almost one of the solutions they presented. Another parameter, graphic relevance, assesses to what extent the drawing describes an idea. In our case, the solution to the given problem. This is performed using a three-level scale:

- Low relevance: Drawing contributes scarcely to the expression of the solution. Level 1.
- Medium relevance: Text and drawing are implied equally in the expression of the solution. Level 2.
- High relevance: The solution is expressed mainly by drawing. Level 3.

This criterion is similar to that applied in other reviewed works. The use of words and drawings is also considered. Julie Linsey [37] studied some idea generation methods according to which form of communication was used by a group: written words only, sketches only, or a combination of words and sketches.

In this sense, graphic relevance is like the quality of the idea (IQ), as both parameters measure the value of the information presented for the expected goal; in the case of IQ, the value of the solution, and for the graphical relevance, the value of the drawing.

2.3. Procedure

Each of the two groups carried out the tests in the same session, during the second half of the 2017–2018 academic year. The first group was in early February 2018 and the second group in mid-February 2018.

For the initial questionnaire, a link to a Google Docs form was provided that the user could access through their mobile device. Knowledge of technical drawing, knowledge of computer-aided design, and declared freehand drawing skills were collected using questions based on a scale from 1 to 3. The data were later collected in a database that facilitated its subsequent analysis.

Once they completed the questionnaire, the participants received a blank sheet in which they input their data and were able to perform the drawing test.

Finally, the problem-solving test was carried out. The participants received a new form in which they input their personal data again and could read the statement of the problem. To achieve this, they had the blank space in the form as well as all the additional sheets they needed.

2.4. Design (Data Analysis)

Qualitative data were recorded according to the study group and analyzed by the research group. One of the team members evaluated the results of the drawing test, while another evaluated the results of the problem-solving test. Subsequently, a review was

carried out by the entire team to ensure the correct evaluation of these results. Finally, and with these revised data, an Excel table was generated to be used for analysis.

The data results from the questionnaire were collected from the online system in which it was designed and reviewed by the research team to seek and remove any wrong inputs. One this was completed, a database was generated.

With all the collected data, a statistical analysis was performed using techniques to summarize and describe the quantitative data, both descriptive and inferential. In the latter case, the data were analyzed with the statistical computer package SPSS version 26.

Although each sample size was greater than 20, the distribution of the data does not correspond to a normal distribution. Therefore, nonparametric Mann-Whitney statistical tests were carried out to compare the following parameters and to find significant differences between Group 1 and Group 2.

- The levels of perspective, dihedral system, dimensioning/tolerances/standards and computer-aided design.
- The declared freehand drawing skill levels.
- The observed freehand drawing skill levels.

To identify any possible relationships between drawing skills and ideation skills, a correlation analysis between the ideation variables (fluency, originality, novelty, idea quality (IQ) and graphic variables (observed freehand drawing skills and graphical relevance) was carried out. Due to the fact that the data does not correspond to a normal distribution and the sample size is not very large, a Spearman nonparametric correlation analysis was performed.

3. Results

3.1. Preliminary Survey

This section shows the data obtained from the analysis of the quantitative and qualitative information collected. Figure 2 shows the levels of engineering graphics declared by the participants in Group 1 and Group 2, respectively. The average obtained in the three subjects for both groups is above the average of the scale (1.5), indicating that all participants in the study think that they have acceptable knowledge and skills in engineering graphics.

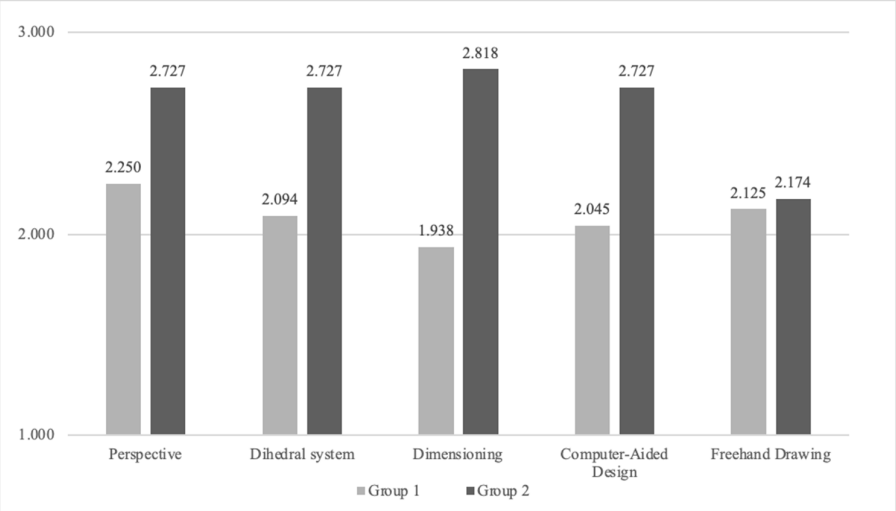


Figure 2. Basic knowledge of engineering graphics and freehand drawing skills as self-perceived by participants.

Freehand drawing skills declared by the participants are also shown in Figure 2. The average values in both groups are just above level 2 (acceptable), which means that all surveyed students recognize that they have a good skill of freehand drawing. The Mann-Whitney test indicated that there were no significant differences ($p > 0.05$) in freehand

drawing skills between the two study groups. However, an interesting observation comparing the freshmen group (Group 1) and the undergraduate group (Group 2), is that there is a clear evolution in the skills and knowledge of perspective, representation systems, and dimensioning/drawing standards, while freehand drawing remains the same. This indicates that students do not perceive a development in freehand drawing skills throughout their degree studies.

3.2. Freehand Drawing Test

Figure 3 shows representative examples of the drawings made by the participants in Group 1. As can be seen, the quality of the drawings is less than desirable. Most of these were made two-dimensional and present errors in the representation of parts, as in the case of the handlebars. The skill in drawing curves was not very precise, and the line of the drawings was discontinuous in many cases.

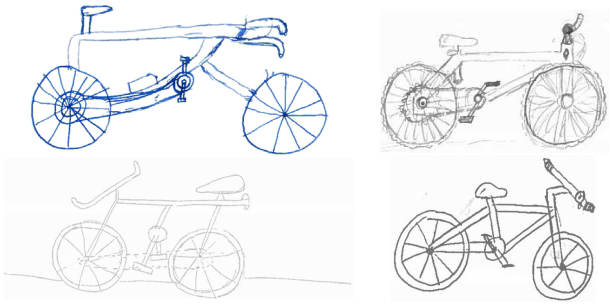


Figure 3. Examples of graphical tests performed by participants (Group 1).

The bicycles drawn by participants in Group 2 (Figure 4) generally showed a higher level of detail, although there were flaws in proportion and representation. The most common flaw was the representation of the handlebars, as in Group 1. There were also errors in the proportion of bicycle elements. Nine participants drew the bicycle in two dimensions. One of the students represented both the views (elevation and plan) of the bicycle. Only three of these cases provide a detailed and proportionate representation of the bicycle. Of the six participants who represented the bicycle in perspective, in only two cases were significant faults identified, both in the projection and in the representation of the elements (e.g., pedals do not connect with the sprocket) or faults in the representation of the handlebars. The rest of the graphic exercises represent a well-projected and detailed bicycle.



Figure 4. Four examples of freehand drawing tests carried out by the students of Group 2.

Table 1 shows the values obtained in the freehand drawing skills appreciating the sketch quality (how the drawing is executed) and the quality of the representation (how the envisioned image is expressed) based on the analysis of the drawings made by the two groups. The same table indicates the values broken down into the quality of the representation (execution of the drawing) and quality of the sketch (expression of the object

from a functional point of view), from the average of which the value of the observed skill variable was obtained. The nonparametric Mann-Whitney test results in the frequency distributions of the two groups being independent (Mann-Whitney U value of 288 and p-value > 0.05).

A low level of freehand drawing skill is observed. Group 1 presents skills near 1 (poor), while Group 2 shows better values, although they are not near the middle value of the range. As it can be appreciated, the differences among groups are clearer and do not reach the expected level that they perceive (near 2: average). Both results contrast with the levels declared by the students (Figure 5).

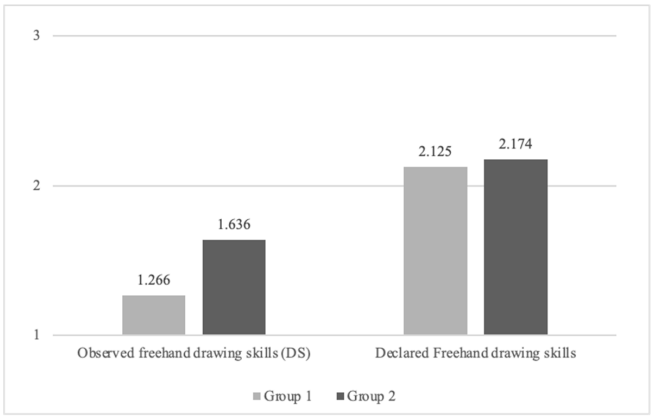


Figure 5. Observed skills vs. declared freehand drawing skills.

3.3. Problem-Solving Test

The results of the problem-solving test in terms of creative performance are shown in Figure 6. Fluency, the number of ideas generated, showed appreciable variations between the participants, being higher in Group 1, which ranged from 1 to 7 solutions, while in Group 2, the number of ideas proposed was mainly distributed from 1 to 5. On the other hand, the average value of the solutions in terms of originality and novelty, as well as the quality of the ideas, was medium to high, all close to 3 on a scale of 1 to 5. However, the values of the idea measurement variables calculated for both groups indicate that, except for fluency (number of ideas generated), no significant variations were observed.

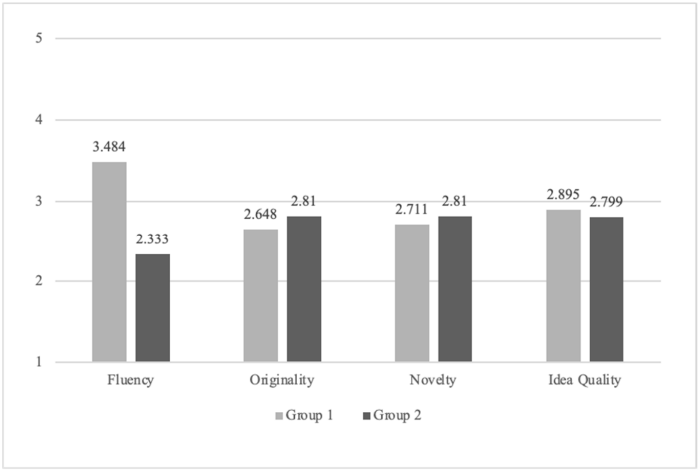


Figure 6. Evaluation of the ideas proposed as a problem solution.

In relation to the solutions presented, the rate of drawings used to express the solutions is shown in Figure 7. It represents the percentage of students who applied drawings in finding the solutions to the problem (graphical students) and the percentage of the solutions obtained that used any kind of drawing (graphical solutions). The use of drawing in

problem solutions is below half percent, as well as the proportion of "graphical students". Remarkable differences were observed in both groups, and students in Group 2 (final-year students) were less likely to use drawings than those in Group 1. However, interesting observations can be derived from these results. First, according to the students, there is a decrease in the tendency to draw among undergraduates. Second, the results in the freshmen group (Group 1) in the percentage of solutions and the percentage of students are similar, but in the undergraduate group (Group 2), while fewer students used drawing, the percentage of global solutions is higher than in Group 1. It can be understood that although the students in Group 2 are less likely to draw, each one applies the use of drawings more than the "drawing students" of Group 1.

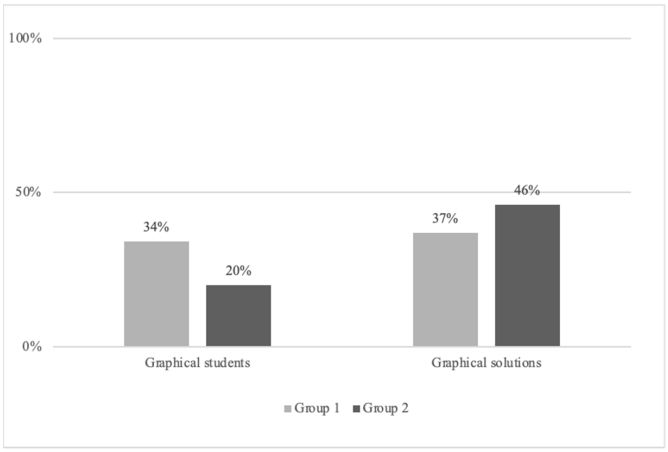


Figure 7. The tendency to draw in problem solving expressed in the percentage of students who draw and the percentage of solutions that used any drawing.

Another important observation is the graphical relevance of the drawn solutions in the problem-solving test. Figures 8 and 9 show examples from Group 1 and Group 2, respectively. In these images, auxiliary elements (e.g., bullets and arrows), as well as text, can be seen together with the drawing. In some cases, the text is an explanation of what the image shows, and in others, the text and the drawing share relevance in the expression of the idea. Both groups showed different results. While in Group 1 the use of graphics is more distributed, Group 2 presents more homogeneous values. In both cases, the graphics applied for the solutions are supported by text, in the worst cases in Group 1 and completely in Group 2.

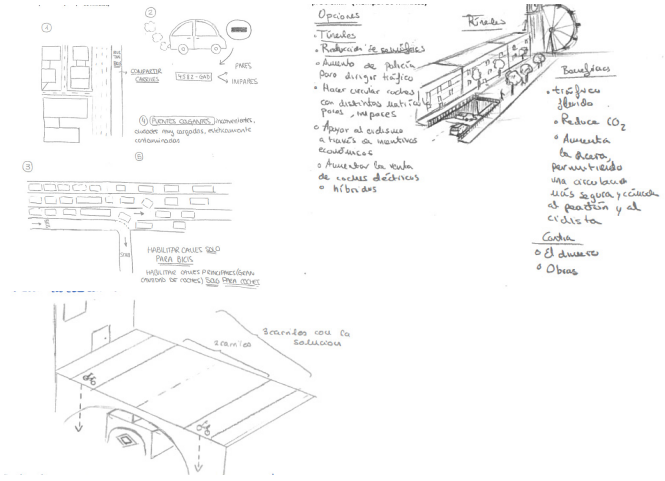


Figure 8. Examples of drawings used in the solutions of Group 1.

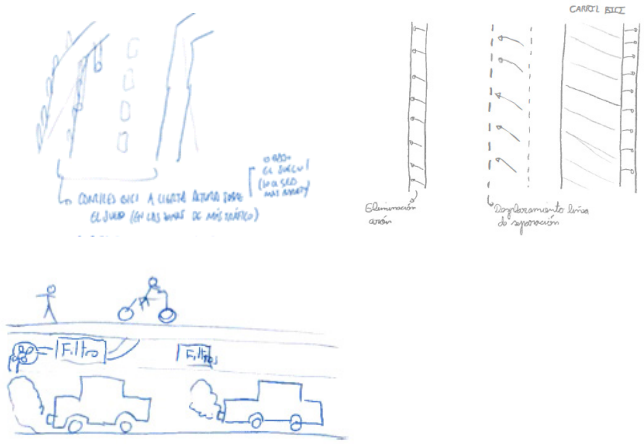


Figure 9. Examples of drawings used in the solutions by Group 2.

This graphic relevance of the drawings as a resource for expressing solutions is summarized in Figure 10 for each group. The results of the rate of drawings used for expressing problem solutions and graphic relevance indicate that, although there is a lower frequency among undergraduates to use drawings to express an idea, they apply them more efficiently, as graphic relevance indicates.

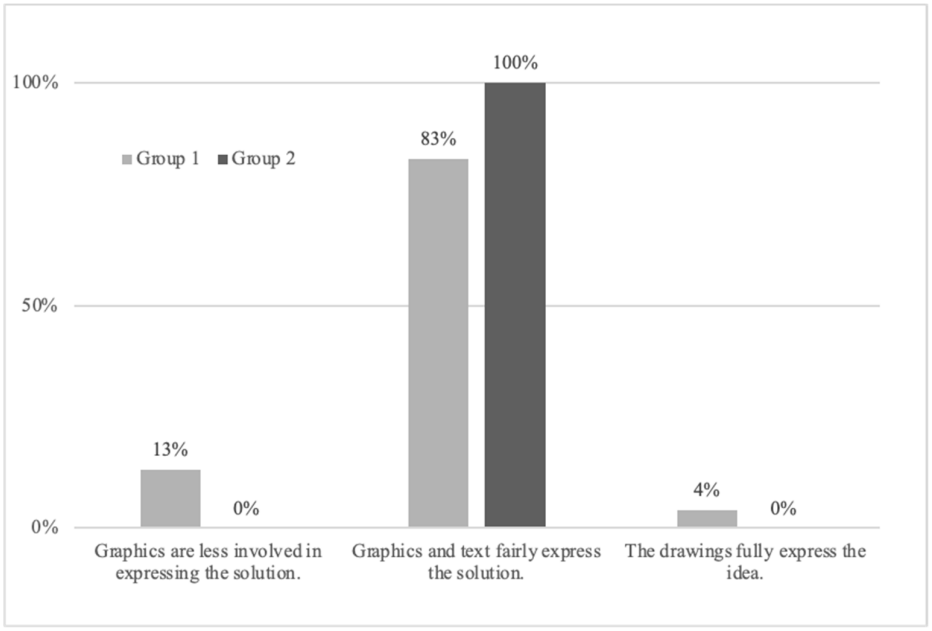


Figure 10. Graphical relevance of the ideas proposed by both groups.

To identify a possible relationship between drawing skills and creative performance, a correlation analysis was carried out. Due to the non-normal distribution of the variables, Spearman's nonparametric correlation analysis was performed. Table 2 shows the test results, represented in the form of a matrix, which also indicates the significance of each case.

As can be seen in this half-matrix, there were only three results of the analysis which gave significant values: novelty-originality, idea quality-fluency, and idea quality-originality. Fluency and originality present a p-value that is closest to being significant ($p = 0.075$), but the correlation value is not high (0.26), similar to the results with novelty (0.203) which is also far from being significant ($p = 0.176$). Novelty and originality are significantly and highly correlated (near to 1) which has a logical explanation due to the similarity of both parameters. On the other hand, idea quality and fluency present a highly significant result, with a correlation value above the middle (0.545). In addition to fluency,

idea quality gives a significant result with originality (0.327, $p = 0.027$) and a correlation result not significant with novelty (0.260, $p = 0.080$). In both cases, the relationship between how original or novel an idea is and its value is lower than expected to confirm a creative performance. Despite this, it gives a notion of how good ideas need to be original.

Table 2. Spearman correlation coefficient hemi-matrix for interrelationships of creative performance and graphical variables.

	Fluency	Originality	Novelty	Idea Quality	Freehand Drawing Skills	Graphical Relevance
Fluency	1					
Originality	0.26 ($p = 0.075$)	1				
Novelty	0.203 ($p = 0.176$)	**0.911 ($p < 0.05$)**	1			
Idea Quality	**0.545 ($p < 0.05$)**	**0.327 ($p = 0.027$)**	0.260 ($p = 0.080$)	1		
Freehand Drawing Skills	−0.060 ($p = 0.691$)	0.196 ($p = 0.191$)	0.1 ($p = 0.51$)	−0.127 ($p = 0.399$)	1	
Graphical Relevance	0.042 ($p = 0.783$)	0.067 ($p = 0.656$)	**0.027 ($p = 0.858$)**	−0.170 ($p = 259$)	0.047 ($p = 0.754$)	1

Finally, none of the ideation parameters, including fluency, originality, novelty, and the idea quality were significantly correlated with freehand drawing skills or the graphic relevance. Specifically, the participants with the highest level of freehand skills did not appear to show better ideas than the other participants. This indicated that being better at drawing freehand had no meaningful effect on helping the generation of ideas. These results suggest that, though the participants' drawing skills varied, they were ultimately less competent in their use of drawing for thinking support. Their abilities to draw did not help them generate more and more diverse ideas in the problem-solving test. Therefore, in this study, the freehand drawing skills of the participants did not significantly influence the experimental results, especially the tendency to draw when solving problems.

It is also important to show that there was no relationship between freehand drawing skills and the graphical relevance (the quality of the drawing used in expressing the solution). As with the creative variables, the correlation value is small and the p-value is far from 0.05, which can be explained by the scarce use of drawing to support thinking by the students.

4. Discussion

The aim of this study was to obtain a notion of the skills of engineering students on how they apply freehand drawing to support visualization concretely on the externalization of envisioned ideas as well as on using drawing for solving problems. In this study, freehand drawing is considered as a tool for visualization which is essential for the development of visual literacy.

This study advocates the need to consider teaching freehand drawing in engineering curricula from a different perspective than it is currently taken. Far from being a graphic expression resource, drawing must be practiced in classes to help with visualization and in the process of solving given problems.

4.1. Skills for Externalization of Ideas by Drawing

The comparison test among the graphic skill levels revealed no relationship between them. This difference between the freshmen group (Group 1) and the undergraduate group (Group 2) is explained because the latter developed their EG skills throughout their training years. An interesting observation gleaned by comparing both groups is that there is a clear

evolution in the skills and knowledge of basic EG (perspective, dihedral representation, drawing standards, and CAD), while freehand drawing remains almost at a similar level. In similar way, regarding the EG knowledge, the expected level of freehand drawing should be closer to 3 (good). This indicates that students do not perceive development throughout their study of an engineering degree.

Causes can be found in the curricula. Manning [28] warned of these observed results, noting that the displacement of other EG topics by CAD may cause the students to lose their ability to visually express what they see in classes and what they generate in their minds. This is an indication of the limited opportunities that students must have during their degree studies. Regarding freehand drawing skills, Julie Linsey [37] remarked that 'in general, engineers are not taught to draw, and their skill in sketching may be lacking'. Uziak [20] warned that the training of freehand drawing skills has been almost eliminated from engineering classes, displaced by computer-aided drafting. The consequences of this were also reported by Peter Varley [38], as engineers are not well experienced in graphically expressing information in an effective manner.

It is observed that the participants in both groups showed lower freehand drawing skills than expected. The results of the drawing test showed low levels in both groups, closer to 1 (poor). However, a slightly higher value on undergraduates is observed, in the same way, explained by the opportunities they find along their coursework, as freehand drawing is not specifically taught.

Our work was centered on determining how skilled students were to represent an envisioned idea by drawing. Mental externalization by drawing was studied early by Yang and Cham [22]. In our case, our interest was focused on mechanical visualization. The importance of being proficient at drawing for visualization support was studied by Miller and Bertoline [4] according to the use of representing dihedral views and vice versa.

The differences in perceived and observed freehand drawing skill level (as they were perceived) and what they really draw are significant. Since all participants feel that they show average drawing skills (level 2), all participants present a level closer to poor (level 1). This is indicative of the state of the question of freehand drawing in engineering education, as well as the consequences of this lack in engineering education.

It is important to review this result considering the observation of Ullman [17], who stated that "most engineers receive no formal training in sketching. It is often assumed to be some natural ability". The risk of this has negative effects in terms of a low level of ability to graphically express an idea, as is shown in our results. This was also warned by Julie Linsey [37] who remarked that 'in general, engineers are not taught to draw, and their skill in sketching may be lacking'.

These 'bad results' were not based on the quality of a freehand drawing, as is generally understood. In these terms, Yang and Cham [22] indicated that: "Sketching ability in the engineering design process is challenging to consider, in part, because of the subjectivity of what constitutes a "good" or a "bad" sketch. Aspects of sketches that are often considered are representational accuracy realism, drawing style, and level of detail". The quality of the drawing in this case and in what sense the mechanical element of whatever the object is and how it works are understood from the graphical representation.

Our study is not focused on improving drawing representation skills, but to develop competence in clearly expressing an idea from the mind's eye. Freehand drawing stands out as the most appropriate resource to help develop visualization skills [15]. Also, it is a fast and effective means of externalizing ideas and actively participating in ideation cycles [16]. Therefore, efforts must be made to teach students how to quickly express images from the mind's eye with the accuracy criteria to transmit how it works far from the aesthetic expression goals. This goal follows the objectives of teaching and learning drawing as a thinking support tool. Some of the benefits can be enumerated [16,17].

Our work was therefore focused on how students were able to clearly represent an envisioned idea by drawing, similarly to the study by Yang and Cham [22]. In our case, the interest was focused on visualization of a mechanical object, but not because there was a

natural affinity of engineers to draw it, as they indicated, but to review its capabilities to express a usual mechanism that they will usually handle.

4.2. Use of Drawing for Problem Solving

Another important observation of this study deals with the proportion in which some type of drawing is used to solve a problem. In the results, we saw appreciable differences between the two study groups. In this sense, it is important to observe the lower rate of drawings presented by the older students, those of Group 2, although each of them individually draws more than the younger students, of Group 1. This observation is consistent with the one reported by Wu [39], as she indicated that senior students are engaged in a visual problem-solving strategy. Regardless, all participants were not very prone to work with visual media when finding solutions to a given problem.

The scarce tendency to draw to solve problems can be analyzed due to several factors. One of these can be sketch inhibition. Hilton [40] warned that the lack of sketch training caused an inhibition in the application of sketches. Booth [23] enumerated several factors that led students to inhibit sketching. These can be personal, intellectual, such as perceiving a real deficiency, social, situational, technological, or based on in-class observations. However, our appreciation is not to cause this low tendency due to any kind of sketch inhibition, but to the lack of awareness of the use of drawings as a support for solving problems. It lies more in inculcating an enhanced 'drawing culture' [19] far beyond simple graphic expression.

Depending on the quality of the graphic solutions and the graphic significance, it is important to remark, as a first instance, the homogeneous results of undergraduate participants (Group 2) of which all of those who expressed graphic solutions did so in an equal manner as text, while freshmen from Group 1 showed more variation in graphic significance. This can be explained by the effect of training on undergraduates, which means influencing students to engage in similar behavior when using this graphic resource. Second, the comparison between the graphic significance of the results of both parameters indicates that, although there is a lower frequency among undergraduates to use drawings to express ideas, they applied it more efficiently.

It is important to consider which type of graphical representation was the most applied—those that were supported by text. According to that, it is important to take into account the findings of Linsey's study [37] with undergraduate engineers, noting that they needed to use verbal descriptions in their sketches, so that they can be interpreted and that this entails an obstacle to their own process of generating ideas. This may explain this trend in the use of combined images and text in graphic solutions. We can consider the formats and techniques of so-called "visual thinking" [41,42]. In these proven techniques, simple drawings are combined with text in the representation of ideas and are also used to solve problems [41]. This applies in different areas, such as education, and is also assessed in engineering classes [43]. Therefore, although this combination with text on drawings can be beneficial in these techniques, in the case of an idea generation process, according to those indicated by Linsey [37] they are not so beneficial. It is important to take this into account for possible teaching strategies aimed at different purposes with the use of drawing.

In this study, these results mean that students who tend to draw when solving problems do not fully develop their visualization skills and abilities when expressing the envisioned ideas. This assertion is supported by several authors.

The correlation matrix showed that there were only significant values between some ideation variables, and there were no differences between skills related to the externalization of ideas (freehand drawing skills, graphic significance) and ideation capabilities (fluency, originality, or idea quality). This indicates that there is no relationship between drawing skills and greater ideation capacity in the evaluated students. In other words, it can be said that the students who were better at drawing and neither the students who used drawing cognitively (graphic significance) were the most creative.

The results contrast with those of Chan [44], who concluded a significant connection between drawing skills and artistic creativity. Our case is related to engineering discipline, which usually uses drawing in a different way and with different frequency than in art education. Additionally, Edens and Potter [45] identified a positive and significant correlation between student 'drawing skill' and mathematical problem solving. Comparing both conclusions with our observations, we can consider the difference between the groups studied (first-grade students) and the specific discipline (arts and mathematics). The case of art and creativity can be explained due to a deeper implication of drawing practice for the creation of artistical outputs, rather than engineering practice, which relies more with analytical works, and those activities more related with creative enhancement are more displaced, leaving fewer opportunities for engineers to find the connection to draw and finding creative solutions.

According to the positive results reported by Edens and Potter [45] between problem solving and drawing skills, their conclusions conflict with those reported by Chan [44], in the sense that artistical drawing is not related to better problem-solving ability, but schematic drawing is. To explain this, it is important to consider that the role of graphics for problem solving in that case was to understand (to "unpack") a mathematical problem ("translation of each sentence of the problem into a meaningful representation"), but not to find solutions creatively, which is the goal of our study centered on this, how being good at drawing can lead to finding original and novelty solutions.

In the case of engineering education, Wu [39] found drawing prompts to be good problem-solving strategies, which increased their use of drawing for this purpose. These prompts help one to conceptually understand a problem, but their study did not focus on how drawing helps to find solutions creatively.

5. Conclusions

This exploratory study focused on visualization supported by freehand drawing, since it is considered an important element in developing visual literacy. Two activities were evaluated in two groups of engineering students: the expression of envisioned ideas by freehand drawing and the tendency to visualize when solving a problem measured by using drawings. The findings led us to finally conclude that engineering students lack the required freehand drawing skills to express envisioned ideas and are not aware of how drawing can help to solve problems.

The similarities of the results among freshmen and undergraduate groups reveal that engineering programs do not encourage freehand drawing practice, and freehand drawing still plays a secondary role in engineering education.

The scarce capabilities for representing ideas by drawing do not allow students to express clearly and quickly what they imagine. These findings are in line with the advice of Uziak [20] who warned that, although sketching is typically considered a relatively simple skill, it cannot be assumed to be a natural ability.

The results also reject the expectation of finding a natural tendency in engineering students to apply drawings when finding solutions to problems. In addition, our study focused on the contribution of drawing practice to find novel and original solutions. Therefore, it is related to creative thinking. Comparing to the findings in research in art education [44], we found no relationship between drawing skills and creative performance in engineering students. If this predisposition to draw as a support for thinking does not exist or is rare, it is considered necessary to promote it in the educational field, given the proven advantages it supposes as an excellent visual media for engineers. That indicates a clear need to reinforce these skills in engineering classes. Students and educators acknowledge this need for an inclusion of freehand drawing training [46]. It is then understood that it is necessary to inculcate students in this use of freehand drawing, as is advocated by Eder [46], Ullman [17] or de Vere [19], as well as Ullman [17] and McGrath [21] pointed out.

As we explained in the introduction, drawing practice for problem solving is considered as a part of the visualization process. Sung [47] concluded a positive influence

on visualization tendency for problem solving. It is also necessary for an engineering education community to perceive the role of freehand drawing to support visualization and the importance of this for future engineers.

Our work was mainly focused on this purpose to spotlight the scarce treatment of drawing skills in engineering education, in what sense it supports cognitive abilities and a need to rethink its implementation considering these benefits, both for graphic expression and for thinking support.

5.1. Implications on Visual Literacy of Students

There is a real need to intensify efforts to improve visual literacy in engineering education. This study focused on a specific aspect that engineers need for visual expression and support for visual thinking. The importance of developing visual literacy in engineering is highlighted, not only in its communication role, but also in the development of visual thinking. In this context, this empirical study aimed to explore an important resource for the development of visual literacy in engineering education around the use of freehand drawing. The results obtained have important implications for how engineering students should reinforce their level of visual literacy in this regard. Since engineering curricula assure students of their knowledge and skills to communicate visually using CAD systems, the traditional form of graphic expression (meaning freehand drawing) is not treated as it should be, in terms of its important role for display support. It is important to raise awareness in the teaching environment of the importance of graphics as tools to support thought, and freehand drawing is a perfect instrument in this regard.

In addition to the data obtained and the results shown, we hope that this work will contribute to improving and promoting the development of visual literacy in engineering students.

5.2. Limitations

Some limitations of the study and some guidelines for future action are presented here. In regard to limitations, it is worth mentioning those related to the samples used. Our intention is to provide a very general overview of what was detected, focusing exclusively on the case of engineering students in the sample selected for the study. This work does not correspond to a categorical study in terms of the visualization performance of engineering students, but it does provide valuable insight into this specific and important aspect, pointing to an issue that should be taken into consideration in engineering education.

5.3. Future Research

The study should be extended to a larger number of engineering schools and could be extended beyond national borders. It would also be of great importance to consider the contributions of a significant number of engineering schools.

Additionally, researchers are encouraged to follow research on the cognitive implications of visual literacy for engineering students. Since the two cases presented on visualization expression are considered as a starting point, we suggest continuing studying feasible pedagogical strategies to foster these abilities. Works by Raudebaugh [15] can be considered, as well as works considering wider perspectives of freehand drawing that encourage creative thinking, such as mind maps [48].

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