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RESEARCH ARTICLE

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Boosting computer-aided design pedagogy using interactive self-assessment graphical tools

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Abstract

Computer-aided design (CAD) tools are essential for any engineer and, thus, many researchers have focused on developing the most suitable method for acquiring CAD competences. In recent years, efforts have been devoted to designing new, innovative and helpful methodologies to improve the CAD pedagogy. The presented research aims at showing the advantages of integrating interactive self-assessment tools into CAD learning methodologies, such as problem-based learning (PBL). One hundred and ninety-one first-year Mechanical Engineering students participated in the research. They were evenly and randomly divided into two groups: a control group and an experimental group. Students belonging to the control group made use of PBL. The experimental group made use of PBL and a new interactive tool, called TrainCAD, that allows the self-assessment of 2D-CAD models designed in AutoCAD. The presented results show that experimental group students have considerably improved their academic performance and increased their motivation on the subject. Therefore, the combination of the two proposed approaches seems to be useful for helping students during the CAD learning process. On the other hand, gender was also a factor that has been analysed, to discern whether it influences the proposed academic learning process (based on the applied CAD pedagogy), concluding that there is no significant influence.

KEYWORDS

academic performance, computer-aided design systems, interactive learning environments, problem-based learning, self-assessment tools

1 | INTRODUCTION

Computer-aided design (CAD) tools have gained great relevance in reinforcing students' education in engineering studies, as it allows them to implement and check technical drawings in a fast and efficient way [18, 21, 34]. However, most CAD teaching techniques comprise the presentation of the main programme commands, and the implementation of specific tutorials [38, 48], which are not enough to evaluate a student's ability to manage

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CAD programmes. Engineering students could use CAD tools to solve almost any engineering problem [37]. Therefore, an important change is needed to introduce CAD basics to the students, away from the behaviourist and didactic methods currently in practice [15].

Problem-solving plays a key role in engineering training [44]. The use of methodologies such as problem-based learning (PBL) can help in CAD pedagogy since it supports students in actively cooperating to solve problems while building knowledge and skills [62, 63]. In the same vein, Garikano Osinaga et al. [24] stated that the use of PBL allows students to work by following the 'learning by doing' concept. In other words, it is very important that the student not only knows how to use CAD tools but can also apply them in context, PBL being a helpful tool in achieving the latter.

CAD pedagogy requires a lot of experience and practice in the use of the different available tools. Although most CAD programmes provide a powerful design environment in which students can try different techniques, their learning progress must be personally checked by the teacher. However, the high number of students attending engineering studies hinders their monitoring in real-time, which complicates the development and implementation of innovative learning methodologies. Therefore, some kind of technological aid would be necessary to allow learning from mistakes [28, 47]. The automatic evaluation of exercises, which provides immediate feedback to the student, could solve this issue [43].

For all these reasons, CAD training needs innovative strategies that not only encourage students to develop skills in the use of these tools but also provide teachers with the possibility of having effective feedback on the CAD pedagogy used. This article aims to identify, analyse and discuss the possible impact of a new learning approach on academic performance and motivation. The approach combines the common methodology employed in engineering studies (PBL) and an innovative self-assessment tool, called TrainCAD, which allows verification of AutoCAD® drawings in real-time.

Therefore, this article tries to answer the following research questions:

- RQ1. *Are there significant differences in academic performance between students who only use PBL and those who use PBL and TrainCAD?*
- RQ2. *Are there significant differences in academic performance by gender between students who only use PBL and those who use PBL and TrainCAD?*
- RQ3. *Is there some relationship between self-assessment exercises and academic performance?*
- RQ4. *Are there significant differences in the valuation of the experience between students who only use PBL and those who use PBL and TrainCAD?*

2 | THEORETICAL FRAMEWORK

2.1 | CAD learning

Most engineering study plans have introduced the use of CAD programmes. In many cases, a traditional learning process is implemented but, recently, novel techniques and technologies have also been applied to the CAD pedagogy with satisfactory results [59]. For example, the CAD learning methodology developed by Purzer et al. [57] is based on the repetition of design sequences, as well as the use of the students' electronic notes. Another innovative methodology was implemented by Peng et al. [55], where students have to teach the use of CAD tools to their classmates. Likewise, the development of a conceptual and visual glossary to help the students to learn important CAD concepts was carried out by Perez-Belis et al. [56].

Due to the scarce time available for teaching the use of CAD tools in educational plans, some authors have promoted the use of Web-based systems to improve CAD training [49, 66], or the combination of off-line and online classes [36]. In this sense, Kallis and Fritz [42] analysed the e-learning tools available for learning CAD and concluded that engineering students have come to accept their use as an essential tool during their engineering training. Another alternative is the use of multimedia tools to complete and support the CAD pedagogy [4]. Indeed, Chen [14] clearly supports the combination of Massive Online Open Courses (MOOC) and traditional classes to improve teaching efficiency. A student-based learning process, comprising the design of screencast tutorials, together with recorded student explanations (who have to share the videos with their classmates for future discussion), was implemented by Peng et al. [20].

Teachers are looking for an easy and familiar interface that may help them with the CAD pedagogy [60]. For this reason, commercial programmes are usually the preferred tools for this purpose. However, with the advancement of technologies, there is a tendency to integrate new tools that complement the traditional CAD pedagogy. For instance, Schwetz et al. [61] promoted the online teaching of AutoCAD in a Virtual environment. Jovanovic [40] developed an online tool for learning Engineering Graphics, through a mobile system supported by a file storage application (Dropbox) and AutoCAD360. Likewise, Timofeeva et al. [68] rely on the use of the cloud

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technology integrated in AutoCAD360 as a helpful tool during the CAD learning process.

The research described in this article makes use of AutoCAD, since it is a worldwide CAD learning tool [50], but it has its limitations. This is why this tool has also been complemented with the self-assessment tools described in this article to facilitate the student-centred learning.

2.2 | Problem-based learning

The introduction of innovative technologies can enhance education. The identification of the best way for transferring knowledge and the best teaching method for acquiring each competence is also crucial [30]. In this sense, PBL has been widely recognised as a methodology capable of engaging students in active learning [5]. Chen [13] stated that the use of PBL can 'motivate students to acquire knowledge and skills by tackling problems and not just to pass exams'. Also, Holgaard et al. [33] supported this methodology, since students learn to act as problem solvers.

As stated by Barrows [12], the main characteristics of PBL are:

- Student-centred learning.
- Tutor assumes the role of advisor.
- Students are divided into small groups supervised by the tutor.
- Self-directed learning.
- Focusing on a real problem.
- Problem used as a tool to acquire the knowledge and skills necessary to solve it.

In addition to these basic characteristics, open learning is another important one, because there is not just a single correct solution [32]. In summary, PBL is a teaching pedagogy in which groups of students learn to solve open problems based on experience and knowledge [8].

All these aspects make PBL an increasingly demanded teaching–learning methodology in engineering studies [69]. For instance, Ariffin et al. [9] implemented PBL in Engineering Drawing through the Fogarty Model approach. This approach suggests seven steps: (1) face a problem, (2) define it, (3) make assumptions, (4) search information, (5) update the problem based on the new information, (6) find solutions, and (7) evaluate them. Moreover, PBL has also been applied to CAD pedagogy. In this sense, some authors supported the use of PBL to improve the students' CAD skills because it could be crucial to promote the autonomous learning and highlight the students' cognitive load [11, 23]. Balan [10] also asserted that PBL methodologies increase student satisfaction, while learning commercial CAD software. Fernandes et al. [22] used PBL for the integration of CAD/CAM/CAE in mechanical engineering curricula, to design a cylindrical movable arm of a commercial aircraft. The results obtained reflected the commitment and enthusiasm of the students on solving the proposed problems, as well as their motivation in following this methodology.

2.3 | Self-assessment and CAD

Assessment plays a very important role in the learning of any subject and, therefore, in the design of the CAD pedagogy to be applied. In this sense, Gelmez and Arkan [25] stated that assessment tasks need to be aligned with CAD teaching and learning activities. However, the current context of engineering studies, where too many students attend classes, reduces the possibilities of properly interacting with the teaching staff [39]. In many cases, this situation leads to resorting to technological resources that help with the instruction and personalised evaluation of the student. Thus, Agost et al. [2] proposed CAD training based on self-assessment through online formative assessment. Other authors have been focused on strengthening the use of Action Research (AR) methodologies in CAD training, through the development of self-learning materials and the use of scoring rubrics to assess the students' CAD skills [7, 30, 72]. Moreover, Company et al. [17] also employed the scoring rubrics as an educational tool to transfer quality criteria from the beginning of the users' CAD training.

Implementing tools that quickly provide assessment results to the students during their learning process, can be an important step towards the success of the CAD pedagogy used. As Malmi et al. [45] indicated, automatic evaluation can be beneficial for both the student and the teacher. On the one hand, the student can continue with their learning, in the knowledge of current progress regarding their acquired skills, at any time. In this way, they avoid unnecessary delays that can affect the quality of their learning process. In addition, learning adapted to the schedules and personal situations of the student is facilitated. On the other hand, the teacher avoids the arduous task of manually reviewing the students' work and adopts the role of a learning facilitator, as specified by the European Higher Education Area (EHEA).

It should be mentioned that it is not easy to get automatic and immediate feedback in CAD pedagogy. Indeed, there are few studies that analyse this problem. Thus, Goh et al. [27] developed a method for evaluating a DXF file created in AutoCAD, converting it to SVG format and using an ad-hoc marking algorithm for

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checking the proposed solution. Pando Cerra et al. [52] designed a web environment to facilitate automatic correction of exercises in the field of Engineering Drawing and CAD. This software was oriented to CAD pedagogy but not from a professional perspective.

The research in this article proposes the use of tools integrated in a professional environment, such as AutoCAD, to directly evaluate 2D models designed by students and, subsequently, return the assessment in real time. In this way, immediate feedback is generated and the student can progress in their learning process.

2.4 | Gender and CAD

Although the amount of females attending Mechanical Engineering studies has increased in recent years, the percentage is still low [53]. Research conducted by Smith et al. [64] determined that female participation in science studies has increased, but it has stagnated in engineering studies. In fact, Minetola et al. [46] estimated a percentage of 10% or less females on each course. There are some studies that analyse the reasons for this low participation. Godfrey and King [26] pointed out that some of the possible factors are: negative opinions regarding engineering studies, wrong prior advice, the lack of female high school students studying prerequired subjects or even masculine biases in engineering curricula and assessment methods. Kadayifci [41] also stated the existence of gender stereotyping as a factor that could affect the low presence of females in these studies. Likewise, Starovoytova and Cherotich [65] suggested the inclusion of support and mentoring activities to increase the participation of females in engineering studies.

However, there are few studies that analyse the gender factor in learning CAD. Agost et al. [1] examined the factors that might affect the students' learning process of CAD and other technical graphics concepts during introductory engineering courses, and noticed important correlations between gender and final exam marks. QaQish [58] concluded that male students developed better perceptions, using CAD, than female students. Pektas and Erkip [54] obtained similar results concluding that males showed a more positive attitude towards the use of computers in design than females. Finally, it should be noted that the research conducted by Akhtar et al. [3] showed significant differences in spatial visualisation between male and female students during CAD learning. Therefore, in line with all of this study, this article wants to analyse whether gender can become a relevant factor when selecting the best CAD pedagogy.

3 | METHODOLOGY

3.1 | Participants

To evaluate the best learning CAD methodology, 191 first-year Mechanical Engineering students have participated. A large sample size was used to make the results more sensitive to any internal variability. The students, aged between 18 and 19, were randomly divided into two groups:

- Control group (CG), where 96 students (77 males and 19 females) learned CAD skills by using PBL.
- Experimental group (EG), where 95 students (73 males and 22 females) learned CAD skills by using PBL and an interactive innovative self-assessment tool for checking the proposed exercises (TrainCAD).

The rate of males and females in both groups was similar (80%–20% in CG, 77%–23% in EG), which facilitated the analysis by gender in this study.

3.2 | Experimental design

In this study, a randomised experiment was adopted to investigate the impact of using PBL and self-assessment tools in CAD pedagogy. Though solid modelling is important in the present CAD systems, many companies still use 2D CAD systems [67]. In this case, first-year Engineering students only receive CAD training in a two-dimensional context, so the expected learning results are focused on developing skills for mechanical drawing, such as the representation and edition of entities, dimensioning of drawings, or the use of printing plan tools.

The experience lasted 8 weeks and the procedure followed is shown in Figure 1. As mentioned, the students were randomly divided into two groups. Before starting the experience, the students of both groups answered a 2D-CAD prior-knowledge test. Likewise, all students received the same theoretical training (five sessions of 1 h each) on orthographic views, sectioning, dimensioning and basic notions of handling AutoCAD (drawing and editing entities, working with coordinates, handling references, dimensioning, layers and blocks, presentations, etc.). An AutoCAD tutorial and a collection of 44 exercises to train CAD tools were also provided to the students.

The students attended a total of seven practical sessions (2 h each) distributed as follows:

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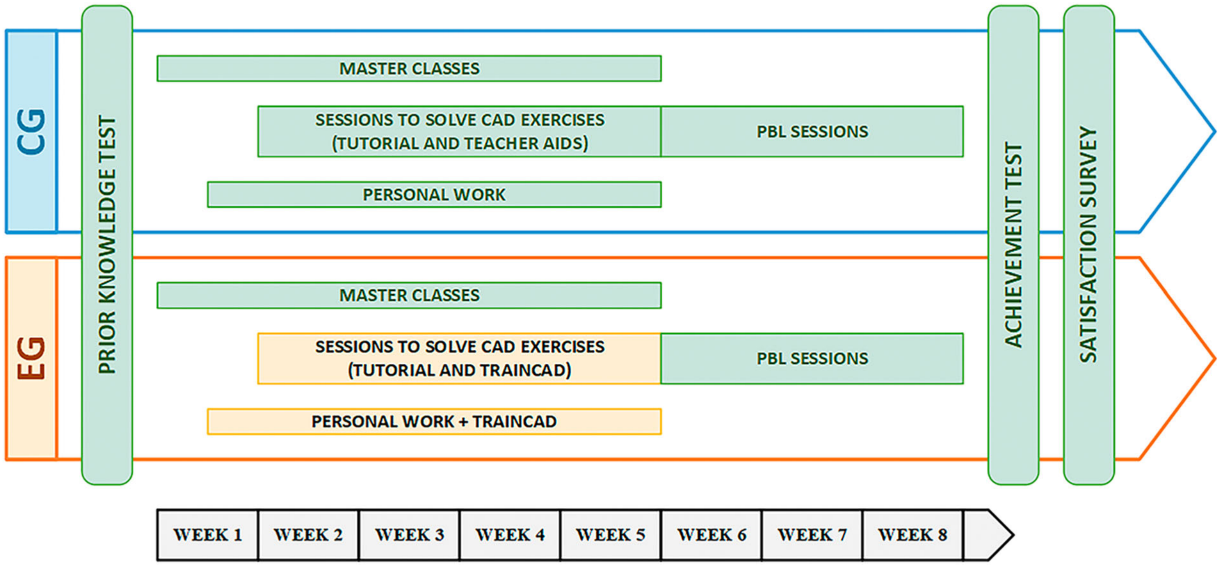

FIGURE 1 Procedure of the experience.

- The first four sessions were devoted to introducing the CAD tools, while solving exercises from the provided collection. CG students solved exercises using the tutorial and the teacher's aid. EG students solved the same exercises using TrainCAD. All the students were able to continue solving the exercises individually, once the face-to-face sessions had ended. The contents studied in these first four sessions are:
  - Session 1 was used to give a general overview of AutoCAD overview, the drawing tools and to use references.
  - Session 2 focused on different editing tools and entity properties.
  - Session 3 aims at explaining the use of layers, blocks, and dimensioning tools.
  - Session 4 was based on the application of Model Space/Paper Space for the creation of plans.
- During the last three sessions, the students in each group were divided into small teams (two to three students). Some 3D models (Figure 2) were proposed to extract their corresponding 2D views (plan, elevation and section views) by using AutoCAD and the PBL methodology. Therefore, the teams had to discuss the best solution, take measures, define views, design the 2D views in AutoCAD and present the solution adopted to the rest of the teams in the session.

The teacher was always available to answer questions or review the results. Once the learning period was finished, the students took an individual final test, focused on assessing the acquired CAD knowledge and skills. Likewise, all students answered a satisfaction survey about the experience.

In summary, all the students in this experience worked on the same CAD competencies and content and all of them were evaluated following the same procedure. The only difference stemmed from the learning methodology, which included the use of an innovative self-assessment tool (TrainCAD) in EG.

3.3 | TrainCAD

Although AutoCAD is a well-known professional CAD tool, it is not properly oriented towards educational purposes. Therefore, a platform called TrainCAD has been designed to facilitate CAD learning. It is a C# library, specifically developed for being loaded in AutoCAD. The most innovative aspect of TrainCAD is its exercise evaluation tool. TrainCAD interacts with AutoCAD to compare the student's proposed solution with the teacher's one by using an accurate entity and property comparison (sensitivity < 0.006 mm), which is a well-known technique that can improve learning effectiveness [19]. The teacher decides what criteria to compare in each exercise: type of entities, geometric parameters (e.g., the centre, the radius, the start angle and the end angle, in the case of an arc), entity properties (colour, linewidth, linetype), layer properties, Model Space/Paper Space properties. A colour code will be used to show the results of the comparison (green = correct, red = error, etc.). Figure 3 shows the evaluation process for an exercise.

As indicated in Section 2.3, previous research to apply self-assessment in CAD learning was oriented to the creation of own tools in other environments. In our case,

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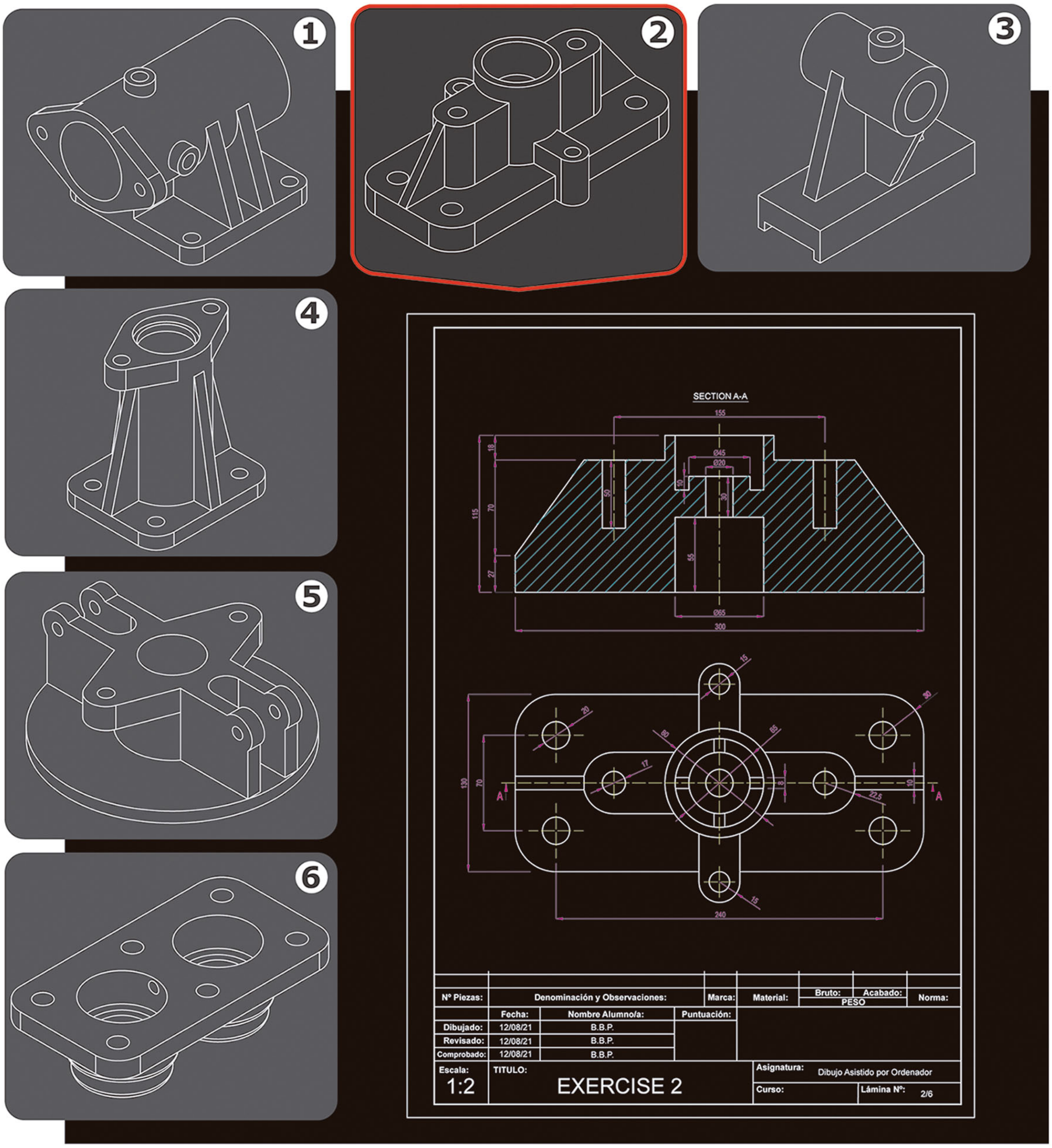

FIGURE 2 Problems with problem-based learning (PBL) sessions.

a tool to integrate into a commercial application such as AutoCAD was designed. For the authors, there is no research with these characteristics in the literature, which implies an important innovation in the study of this subject.

TrainCAD consists of four modules (Figure 4):

1. RESOLUTOR: In this module, the users can solve the proposed exercises by using AutoCAD tools. Once an exercise is finished the self-assessment tool integrated in TrainCAD can be used to automatically assess it. Moreover, TrainCAD also stores other parameters, such as time to complete, dates or number of attempts.
2. TRAINER: Similar to the RESOLUTOR but, in this case, the exercise assessment is conducted step by step. Indeed, the student cannot progress until the system checks the current step or command. In this way, techniques and procedures for the use of the CAD tools can be trained.
3. REPOSITORY: Students have a repository from which they can download complementary material (exercise questions, manuals, etc.).
4. PROFILE: students can visualise their personal information, modify their data access, view their history and download detailed reports of their work in TrainCAD.

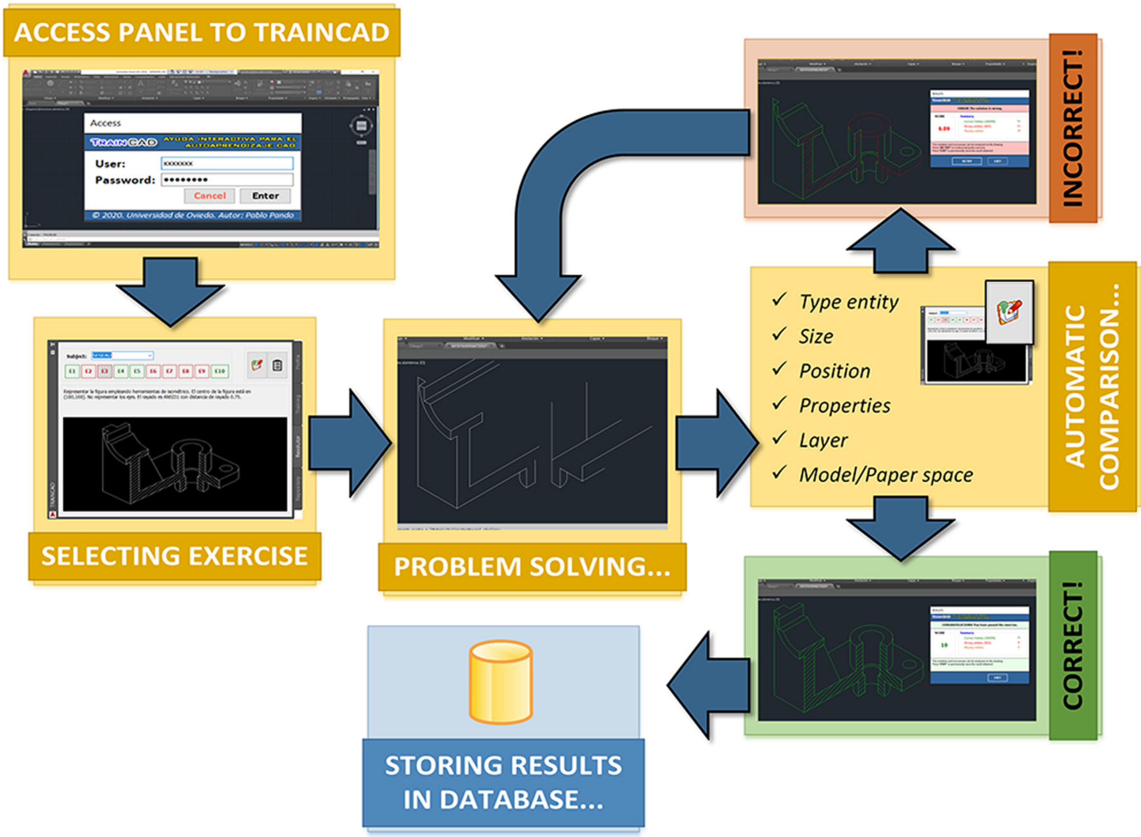

FIGURE 3 Evaluation process in TrainCAD.

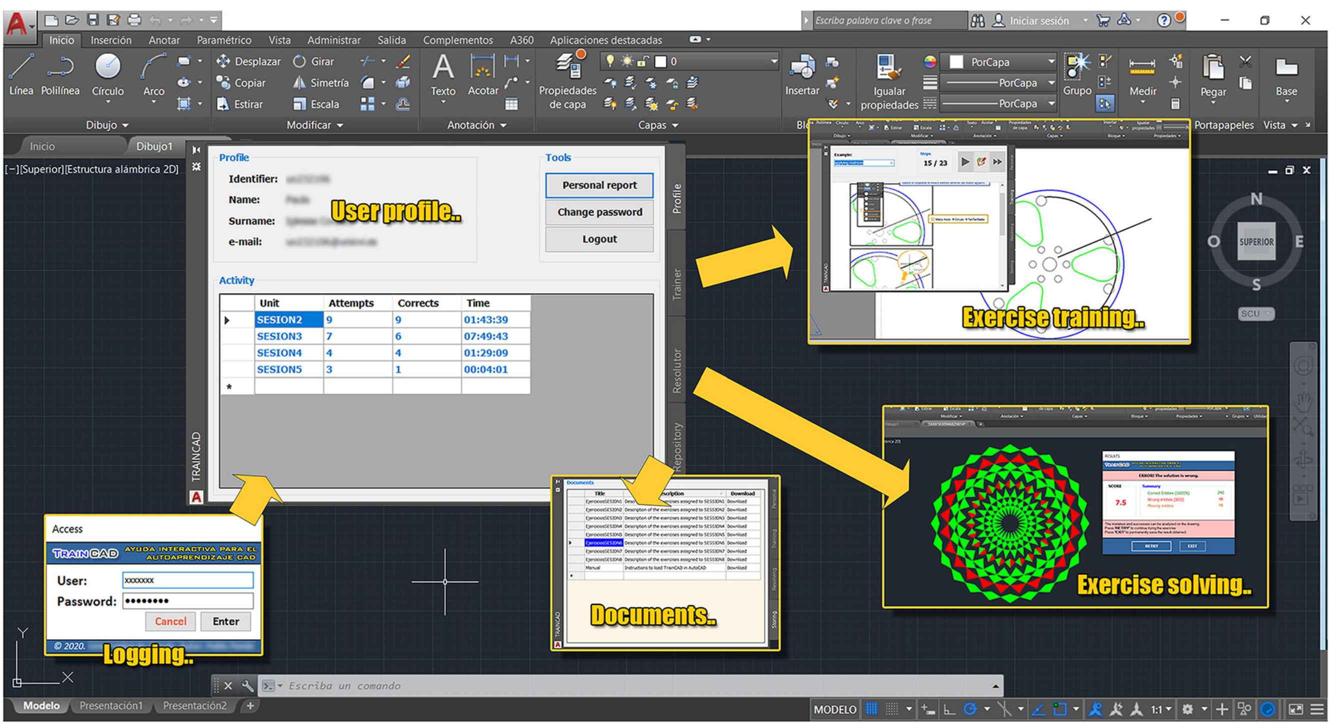

FIGURE 4 Modules of the TrainCAD client.

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TrainCAD is complemented by a web management console (Figure 5) that allows the teacher to analyse the recorded information in the database, to manage control functions (such as the accounts and the content management), to assign new content to users, to monitor the work of each user or group of users in real-time and to generate statistics and reports (Word or Excel) from the stored data.

3.4 | Research instruments

3.4.1 | Prior knowledge test

An anonymous questionnaire was proposed to measure the prior 2D-CAD knowledge of the participants in this experience. It consisted of 20 multiple-choice items with four options each (see Appendix A). Only one of these options was correct. The scale had a high level of internal consistency, as determined by a Cronbach's α of .721.

3.4.2 | Achievement test

The achievement test consisted of drawing 2D views in AutoCAD, which was similar to those made in the last three practical sessions (Figure 2). The test had a 2-h duration and was manually assessed by the same teacher, with a mark from 0 to 10. The evaluation criteria (format and views, entities, layers, dimensioning, etc.) were clear and identical for all of the students.

3.4.3 | Satisfaction survey

An anonymous questionnaire (Appendix B) was designed to evaluate the degree of satisfaction of the students with this experience. It adopted a 5-point Likert-type scale from strongly disagree (1), disagree (2), neither agree nor disagree (3), agree (4) to strongly agree (5). The internal consistency of the survey has been estimated as high (Cronbach's α of .838).

3.5 | Data analysis

Quantitative data were collected for the analysis and descriptive statistics were used to describe them. Different statistical analysis was carried out to examine significant behavioural differences between the students of the CG and EG groups. Analyses were conducted using the SPSS programme (version 27.0.1.0). Thus, the results of the achievement test were analysed by methodology and gender, to answer RQ1 and RQ2. The results of the achievement test and the number of exercises solved with TrainCAD in EG were compared

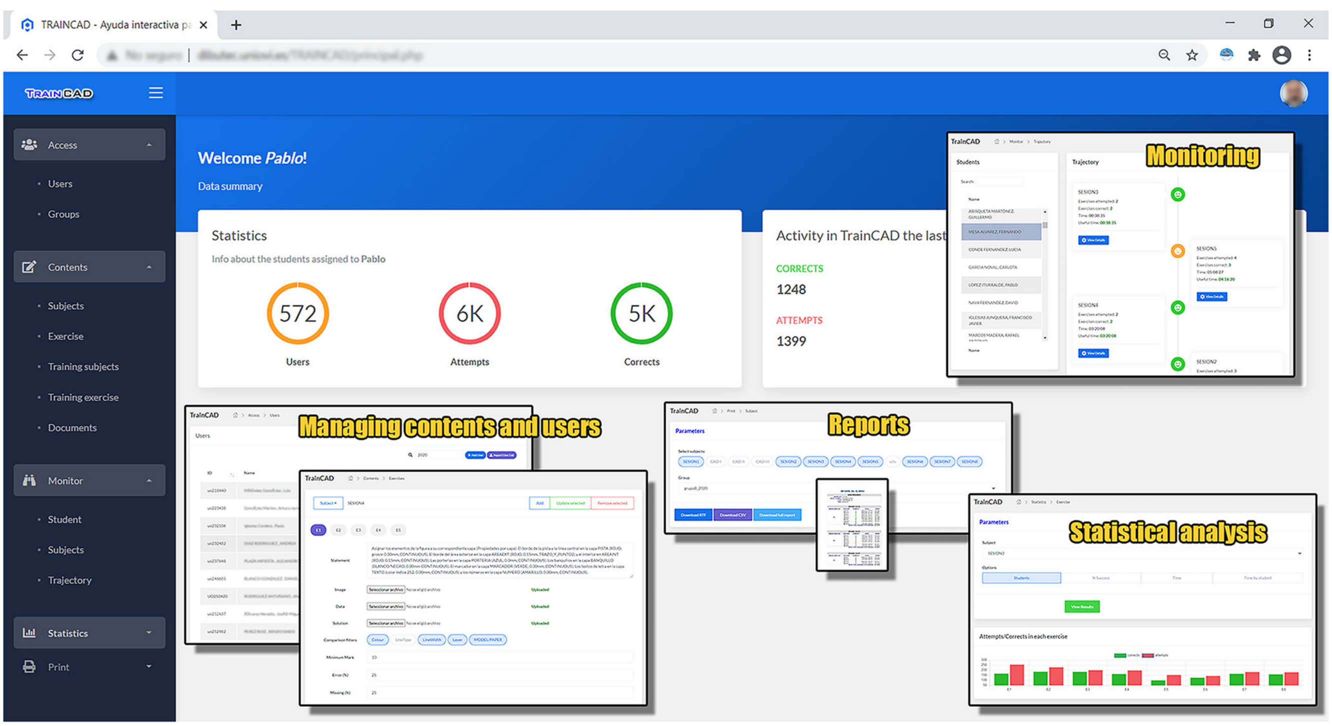

FIGURE 5 TrainCAD Management Console

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with answer RQ3. Finally, the results of the satisfaction survey at the end of the experience were analysed to answer RQ4.

4 | RESULTS

4.1 | Prior knowledge test

An independent-samples *t* test was run to determine whether there were differences in prior 2D-CAD knowledge between CG and EG students. Figure 6 shows the results of the test, grouped by the number of correct answers. Figure 7 shows the results of the test by item. There were no outliers in the data, as assessed by inspection of a boxplot. Scores were normally distributed for CG with a skewness of 0.182 (SE = 0.246) and kurtosis of −0.485 (SE = 0.488) and for EG with a skewness of −0.643 (SE = 0.247) and kurtosis of −0.842 (SE = 0.490). In addition, there was homogeneity of variances, as assessed by Levene's test for equality of variances ($p = .906$). The results obtained were quite similar in CG (M = 5.84, SD = 3.39) and EG (M = 6.19, SD = 3.31). The differences between both groups were not statistically significant, M = 0.346, 95% CI: [−1.30, 0.61], $t(189) = -0.712$, $p = .477$.

4.2 | Achievement test

A two-way analysis of variance (ANOVA) was conducted to examine the effects of gender (GENDER) and type of methodology (GROUP) on academic performance (SCORE). Table 1 and Figures 8–10 show the analysed data for further clarification. Residual analysis was performed to test the assumptions of the two-way ANOVA. Outliers were assessed by inspection of a boxplot and normality was assessed using a Lilliefors-corrected Kolmogorov–Smirnov test for each cell of the design and the homogeneity of variances was assessed by Levene's test. There were two outliers in CG, assessed as being greater than three box-lengths from the edge of the box in a boxplot. However, it was decided to keep them in the study and they will be commented on further, in Section 5. In addition, residuals were normally distributed ($p > .05$) and there was homogeneity of variances ($p = .095$).

The interaction effect between gender and type of methodology on academic performance was not statistically significant, $F(1, 187) = 0.228$, $p = .634$, partial $\eta^2 = 0.001$. When analysing the main effect of gender on academic performance, it was determined that there was no statistically significant difference, $F(1, 187) = 0.492$, $p = .484$, partial $\eta^2 = 0.003$. In addition, the value for Partial η^2 indicates that a very small proportion of variance can be explained by the effect of gender on academic performance. This would mean that the effect of the methodology applied is the same for males and females. Therefore, an analysis of the main effect for the type of methodology was performed, which indicated that the main effect was statistically significant, $F(1, 187) = 7.187$, $p < .05$, partial $\eta^2 = 0.037$. All pairwise comparisons were run where 95% confidence intervals

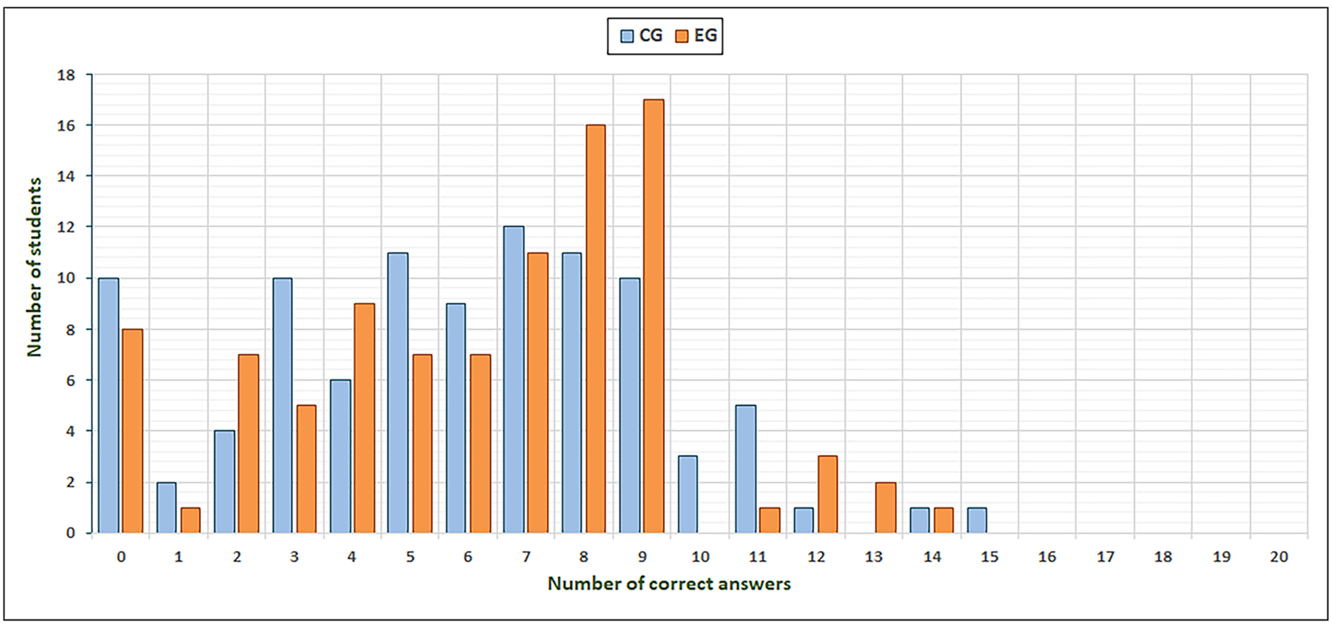

FIGURE 6 Results of the prior knowledge test with the number of correct answers.

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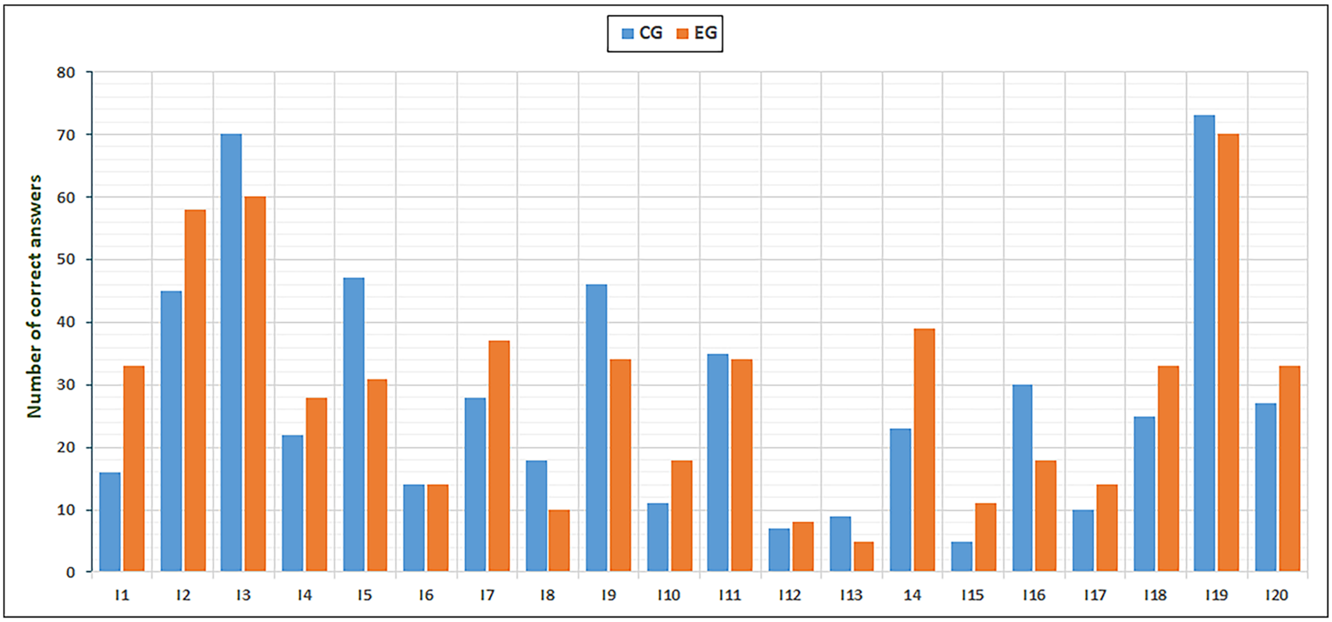

FIGURE 7 Results of the prior knowledge test by item.

TABLE 1 Results of the achievement test

		n	*M*	*SD*	*Mdn*
CG	Male	77	6.45	2.32	6.50
	Female	19	6.54	2.42	7.00
	Total	96	6.48	2.33	6.73
EG	Male	73	7.27	1.84	7.38
	Female	22	7.70	1.51	7.66
	Total	95	7.37	1.78	7.50

Abbreviations: CG, control group; EG, Experimental group.

were reported and *p*-values are Bonferroni-adjusted. The unweighted marginal means of the SCORE for CG and EG were 6.50 (SE = 0.267) and 7.48 (SE = 0.253), respectively. Likewise, EG was associated with a mean SCORE 0.98, 95% CI: [0.26, 1.71] higher than CG, and a statistically significant difference, $p < .05$. In this case, the measure of partial η^2 suggests a medium effect size to quantify the difference of the academic performance by the type of methodology used.

4.3 | Exercises solved with TrainCAD

A Pearson's product–moment correlation was run to assess the relationship between the academic performance (SCORE) and the number of exercises solved by TrainCAD (NEXERCISE). As noted above, 95 EG students were recruited to this analysis (see Figure 11). Preliminary analyses showed the relationship to be linear with both variables normally distributed, as assessed by the Shapiro–Wilk's test ($p > .05$), and there were no outliers.

There was a statistically significant, highly positive correlation between both variables, $r(93) = 0.77$, $p < .001$, with NEXERCISE explaining 59.7% of the variation in SCORE.

4.4 | Satisfaction survey

A nonparametric test is appropriate when the outcome is an ordinal rank, such as the questionnaire used in this study (5-point Likert-type scale). Therefore, a Mann–Whitney *U* test was run to determine whether there were differences in the valuation of each item in the satisfaction survey between CG and EG students. Distributions of the valuations for both groups were similar, as assessed by visual inspection. Table 2 shows the results obtained. The analysis concluded that the valuation was statistically significantly higher in EG than in CG, in five of the nine items (IT4, IT6, IT7, IT8 and IT9).

5 | DISCUSSION

5.1 | Prior knowledge about CAD

First, the initial test confirmed that the students in both groups started the experience with a similar CAD

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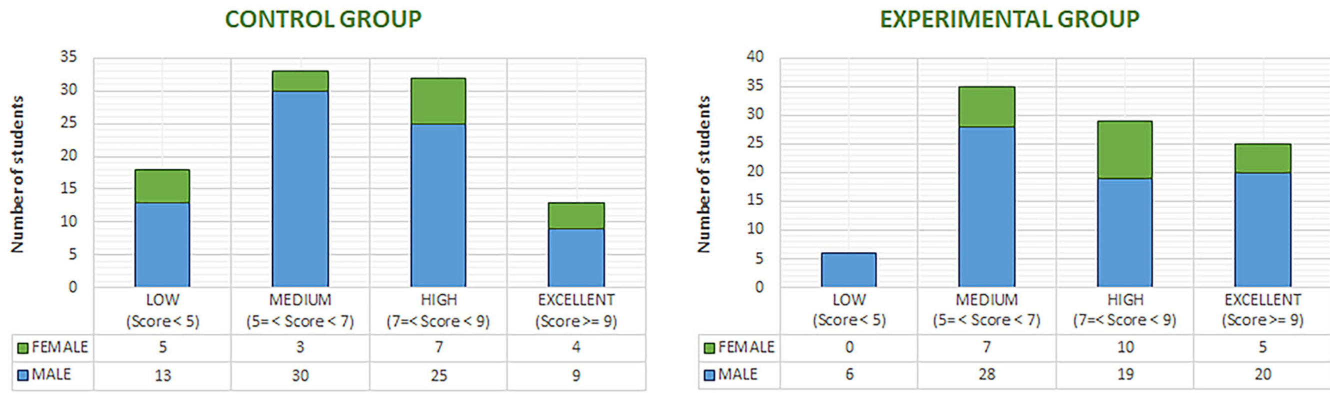

FIGURE 8 Results of the achievement test score grouped by categories.

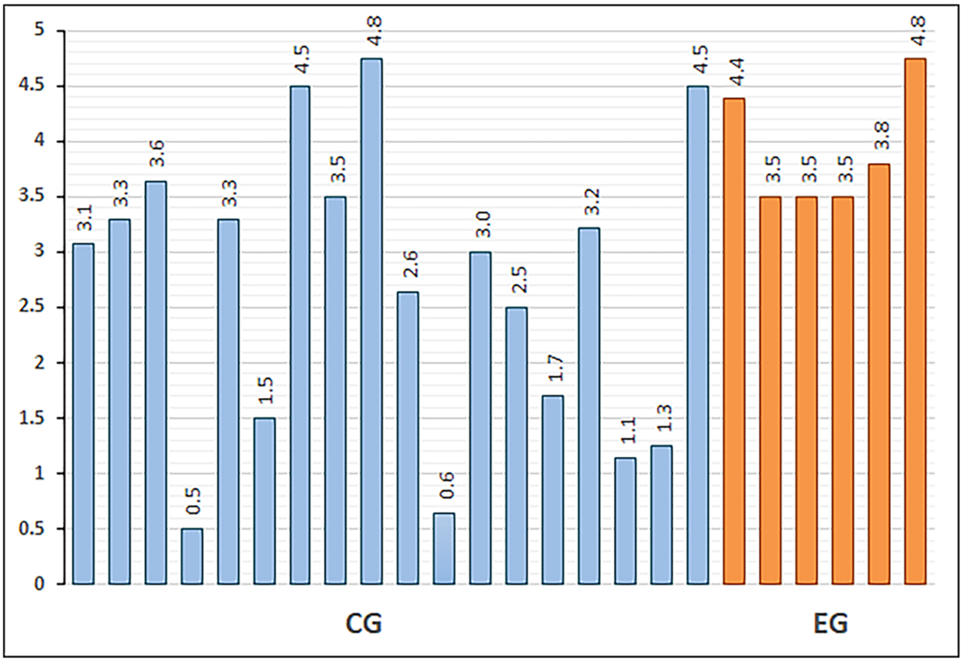

FIGURE 9 Marks of the students in LOW category (score < 5 points) of CG and EG.

knowledge level. Less than 10% of the students had previously used these tools (11 of 96 in CG and 7 of 95 in EG answered at least 50% items correctly). Furthermore, the few students who passed the test did not demonstrate a high degree of knowledge (all answered less than 16 items correctly). By deeply analysing Figure 6, a similar number of students did not answer any of the questions correctly (10 EG vs. 8 CG). Concerning the students who answered either 1–3, 4–6 or 10–15 questions correctly, they were the same in both groups. Although the students who answered 7–9 questions correctly were slightly different in both groups, this is not considered a significant difference, in general terms. Consequently, it can be concluded that similar results have been observed in both groups.

Analysing the results of each of the test questions (Figure 7), no remarkable differences are noticeable in both groups either, which confirms the high internal consistency observed during the statistical analysis. In addition, it should be mentioned that there are questions with related concepts, on which the students' answers are not clearly correlated as expected (e.g., questions I1 and I10). Therefore, it can be concluded that many students have answered the questions randomly. This is further corroborated by the correct answers obtained in the CAD-specific questions, which cannot easily be deduced, for instance, a reduced number of students correctly answered questions I12, I13, I15 or I17.

As the test was anonymous, it cannot be detected whether there is a correlation between the prior 2D-CAD

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knowledge of the participants and the results concerning the acquired knowledge by each student in a group. Nevertheless, the obtained results and the statistical analysis enabled the conclusion that the initial knowledge of the students in both groups was similar. All the aforementioned reasons support the fact that the students developed their CAD knowledge and skills because of the methodology and tools presented in this experience. In addition, no external or internal factors have been detected that could significantly affect the CAD pedagogy analysis.

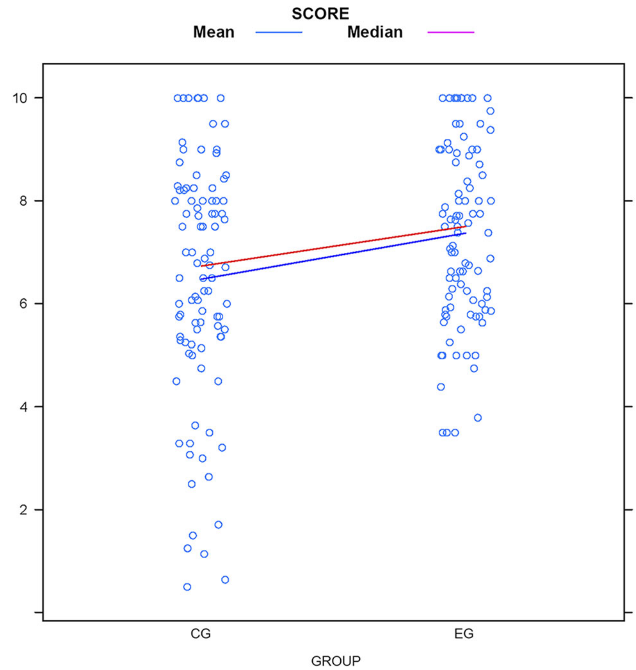

FIGURE 10 Relationship between the SCORE and GROUP variables.

5.2 | Academic performance

Regarding the achievement test, an outstanding difference between the mean marks obtained by the students in each group during the assessment is observed. EG, whose students employed TrainCAD for their learning process, obtained a mean mark 0.88 points higher than the students in CG, who only used the conventional learning methodology. Although the previous point is noticeable, there are other relevant aspects regarding the students that failed the test (LOW category). For the CG group, there were 18 students in this category (18.75%), whereas only 6 students in the EG group failed the test (6.32%). Consequently, there was a noticeable increase (12%) in the number of students in the EG group that passed the test. In addition, although some EG students obtained low marks, none of them were below 3.5 points (see Figure 9). However, most of the low mark results obtained by the CG students were below 3.5 points. An in-depth analysis of the test results revealed that the main problems were related to the basic construction phase (drawing and edition of entities). Indeed, some students were not prepared enough to tackle this task, which also affected the correct use of other tools based on the drawing entities, such as the use of layers or annotation. Despite all the students receiving the same theoretical lessons, in CG there was not the exhaustive control that occurred in EG, regarding how the students in CG applied the learned CAD contents. The latter could

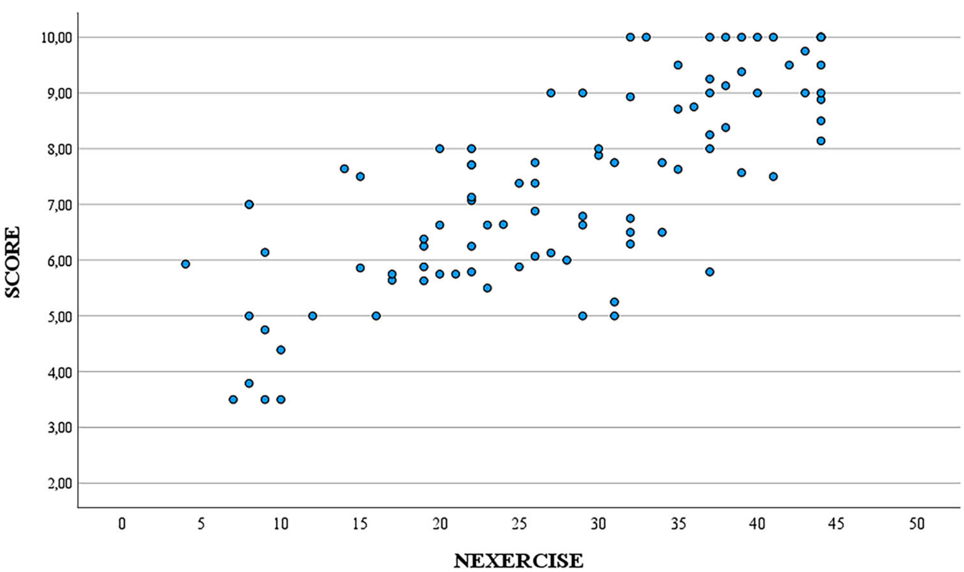

FIGURE 11 Relationship between the SCORE and NEXERCISE variables.

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TABLE 2 Results of the satisfaction survey

	CG (*n* = 96)			EG (*n* = 95)			Mean difference	U	z	p
	M	*Mdn*	*SD*	*M*	*Mdn*	*SD*				
IT1	3.29	3.00	0.951	3.26	3.00	1.02	0.03	4473.00	−0.241	.810
IT2	3.45	3.50	1.09	3.41	3.00	1.03	0.04	4379.50	−0.493	.622
IT3	3.69	4.00	1.06	3.71	4.00	1.04	0.02	4513.50	−0.127	.899
IT4	2.76	3.00	1.09	3.28	3.00	1.09	0.52	3398.50	−3.157	.002
IT5	3.17	3.00	1.24	3.24	3.00	1.05	0.04	4420.50	−0.377	.706
IT6	2.99	3.00	1.21	3.61	4.00	1.07	0.62	3243.00	−3.566	<.001
IT7	2.90	3.00	1.07	3.48	3.00	1.11	0.58	3282.50	−3.486	<.001
IT8	2.97	3.00	1.03	3.42	3.00	1.19	0.45	3542.00	−2.758	.006
IT9	3.11	3.00	1.06	3.74	4.00	1.00	0.63	3115.50	−3.943	<.001

explain why a high number of students did not reach an adequate level of CAD experience to properly manage the CAD tools and pass the test. On the other hand, the students in EG acquired better knowledge of basic construction although, in some cases (only 6), it was not enough to pass the test. Considering that the only difference in the learning process was the use of TrainCAD by the EG students, the statistical analysis revealed that both groups had different behaviour. Therefore, it can be concluded that the difference in the students' marks could stem from the introduction of self-assessment tools into the learning methodology analysed in this study. The validity of the measure obtained in the statistical analysis also seems to corroborate this statement, since a certain correlation between the academic performance and the type of methodology has been detected.

It was also observed that the distribution of students belonging to the MEDIUM (34% in CG and 36% in EG) and HIGH (33% in CG and 31% in EG) categories are similar in both groups. However, the students who reached the EXCELLENT category, whose marks were equal to or greater than 9, increased 13% with respect to the students in CG. Consequently, from the research results, a clear improvement of the EG students' marks was observed, as they obtained a better mean mark, a lower fail rate and higher marks.

How did TrainCAD affect these results? TrainCAD allowed greater control over the level of knowledge in the use of CAD tools. The students knew in real time whether they had used them correctly. Therefore, immediate feedback was obtained, which is difficult to achieve with the conventional procedure. This could be a crucial support for students who may have doubts regarding their learning progress. Likewise, it could also be related to the two outliers detected during the statistical analysis. First of all, it was observed that the students could not attend all of the first practical sessions for personal reasons. This involved a significant delay in their learning process, since it was difficult to adapt their schedules to those practical sessions. Each student has a different learning pace and some of them demanded their own pace. In fact, as indicated by Gracia Ibanez and Vergara Monedero [29], it is essential to attend to the students' demands to improve CAD teaching. Consequently, a tool that allows students to work at their own pace, from different locations and at the same time, which can also provide personalised content adapted to each student needs, is crucial. TrainCAD properly fulfils the aforementioned requirements by means of its content management and its real time learning control tools. Moreover, the real time monitoring of the students learning, provides the teacher with the ability to swiftly interact with those students that need additional help to solve certain doubts or questions during the learning process.

5.3 | Learning CAD and gender

The percentage of female students in this experience was much higher (more than 20%) than the average in the mechanical engineering studies mentioned above. Furthermore, females are evenly distributed in both groups. These two indicators are very positive because they allow a statistically more comprehensive discussion of the results obtained during the experience.

Analysing the results in terms of gender, similar marks were observed in the CG group (6.45 males and 6.54 females), whereas females in the EG group obtained almost half a point higher than males (7.27 males and 7.70 females). In addition, it was observed that no female

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failed the subject. By studying the available stored parameters in the TrainCAD database, it was observed that females in the EG group devoted more time to prepare the subject than males. Furthermore, the mean number of exercises tried by females (31.55 exercises) was significantly higher than the ones tried by males (27.06 exercises). Moreover, although the number of females in EG (23%) was considerably smaller than the number of males, the percentage of tutoring was remarkably greater (17% more). Taking into account that the statistical analysis did not reveal different behaviour in terms of gender, the obtained results could show that the females in EG had greater motivation than males. Although both males and females in EG obtained improved marks, females seem to better understand the work mechanism. The latter is even more evident when we consider the similar marks observed for males and females in CG.

5.4 | Relationship between self-assessment and academic performance

Statistical analysis in EG also determined that there is a significant relationship between the number of exercises solved with TrainCAD and the academic performance. The students who had solved the major amount of training exercises in TrainCAD scored the best results on the achievement test. In other words, the self-assessment tasks enabled by TrainCAD are useful for preparing for the evaluation process. This is in line with the research conducted by Veerasamy et al. [70] who concluded that students' solving skills can be used to determine their final exam performance. In addition, TrainCAD provides additional information (number of attempts or time to complete the exercises) that does not have a direct impact on academic performance (the programme only monitors the access time to each exercise, not the effective working time), but can give an approximation on the time required for acquiring the needed CAD knowledge, especially the time spent outside of the class.

5.5 | PBL and self-assessment

The design of high quality plans is a fundamental aspect during the development of technical documentation in engineering projects. The choice of PBL to acquire this skill seemed appropriate, since this methodology is a good way to stimulate students into seeking the theoretical and practical framework to collaboratively solve problems that do not have a single solution. This experience attempted to teach engineering students to draw and not just to use CAD commands. However, Hamade and Artail [31] stated that there are some students who easily acquire CAD abilities, whereas others experience certain difficulties. TrainCAD was developed to support the used learning methodology (PBL), so that students acquire the necessary CAD skills to successfully solve the proposed problems in the last three practical sessions. In this way, greater control of the students' knowledge level is achieved before tackling these tasks. By conducting proper training in CAD tools, students gain confidence and can focus their efforts on working on other very important engineering skills, such as problem solving, teamwork and communication skills. In fact, research conducted by Vidic [71] confirmed that engineering students have positive attitudes towards cooperative learning and towards the use of computers in problem-solving. Therefore, prior use of TrainCAD could be the scaffold upon which to boost students' confidence in achieving their goals using PBL. Indeed, the results obtained in this study support this statement.

The use of PBL also influences the academic performance of the participants in this experience. For this reason, the possibility of mixing CG and EG students in the three PBL practical sessions was studied. However, this option was discarded as the results would have been diluted within the general data of the experience and, hence, the area of influence of this tool could not be clearly defined in the used CAD pedagogy. In this way, the use of PBL affected the academic performance of all students equally.

5.6 | Valuation of the experience

The first interesting result provided by the statistical analysis of the satisfaction survey is that, statistically, significant differences were only detected in those items where TrainCAD had been used. First, EG students valued the methodology and tools used for solving exercises (IT4) in a more positive way (more than 0.5 points) than CG students. Furthermore, the CG students gave it the worst score in the entire questionnaire. When asked about the most significant aspect that facilitated their learning in CAD tools, EG students were clear: the self-assessment tool. They highlighted that they felt additionally guided during the individual learning process, resulting in extra motivation to keep with their studies. In contrast, CG students did not significantly highlight any aspect of their learning and opted for the general procedure, as a whole. In addition, they were clear when asked about the negative aspects that stood out the most in this experience: the slowness of feedback during the exercise-solving process. It is true that the

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learning pace is managed by the students, who have to solve the proposed exercises. However, the teacher is in charge of guiding the students to develop their learning strategies and check that this learning is on the right track. This could cause a significant delay by hindering the progress of all students at the same time.

These possible learning delays are also related to two other items in the survey (IT6 and IT7), on which response times to the proposed CAD pedagogy were assessed. Both items obtained very positive responses from EG students, surpassing the other group by more than 0.5 points. Furthermore, the valuation by the CG students did not reach 3 points in either of the two items. Regarding this aspect, there are several authors that promote the use of assessment tools in CAD, as a quality manual revision takes a lot of time, which is sometimes unaffordable for many teachers [16, 35]. Indeed, it should be noted that the information and guidelines provided during the learning process are more effective, as they significantly reduce the time between exercise completion and feedback [6]. A clear reduction in the revision periods is not possible with the traditional learning methodology. In fact, the students belonging to the CG had to wait for the teachers' revision of their exercises, which clearly delayed the response to the possible questions that may arise during the solving of the exercises. In addition, if the teacher has a significant number of exercises to revise, there could be long delays in the students' learning process. Consequently, students may experience certain anxiety or they could lose interest in the subject and, hence, there could be a clear delay in the CAD pedagogy. It should also be noted that teachers always have the same number of master classes to teach the subject. However, the content that has to be taught usually increases and changes to a greater or lesser extent, depending on the subject. Therefore, it would be crucial to have tools that analyse and optimise, not only the dedicated time in the lecture room but also the students' self-learning. However, to achieve the latter, it is crucial to have detailed information of the learning process of each student for monitoring and properly guiding them. All the previous key aspects were considered during the development of TrainCAD. This environment provides a unique perspective for the teacher, who can analyse the impact of each proposed exercise on the students' learning. Moreover, students have the opportunity to schedule their own learning without having to wait for the teacher's response.

Regarding the assessment method used in each group (IT8), notable differences in opinion were also observed between both groups (EG surpassed CG by 0.45 points). These differences could probably be more conditioned by the new element included in the assessment process (TrainCAD), rather than by the assessment of the achievement test. Furthermore, the perceptions of each group regarding the acquired knowledge and confidence for solving the proposed exercises were quite different. EG students felt more confident in facing the achievement test, because they had previous indicators of how well their learning of CAD tools (TrainCAD) had been. Therefore, they mainly focused on preparing the part of the subject in which they applied PBL (2D plans). On the other hand, the CG students arrived with more doubts about the test, primarily regarding whether their previous learning was satisfactory. In addition, teachers also benefited from using TrainCAD. The information stored in the TrainCAD database allowed them to easily identify those elements of CAD learning that might be most difficult for each student.

Regarding the general assessment of the experience (IT9), the results were also very significant, with an appreciable difference in the perceptions between both groups (3.11 CG vs. 3.74 EG). Therefore, EG students felt more satisfied with the followed learning procedure, as reflected in the survey.

Another interesting aspect that must be highlighted in this experience was the reduction in the dropout rate. Four EG and 11 CG students gave up the course before the first week and did not participate in the study. In the case of CG students, the dropout rate was similar to the previous courses (around 10%), which makes sense because the same methodology had been employed. Consequently, it can be concluded that the usual, growing, dropout trend was notably reduced, coinciding with the integration of self-assessment tools in the learning methodology. It is true that there is no conclusive data on whether the use of these tools had been the cause of this change. However, the results obtained in the satisfaction survey could support this approach, or at least lay the foundations to change that trend in the future.

Finally, it should be noted that the items in which no significant differences were detected, correspond to common aspects of the two learning strategies used. Furthermore, the differences between the mean marks of both groups in these items were minimal (less than 0.05 in all cases), as shown in Table 2. As indicated in the procedure, all students have access to the same content. All students evaluated positively (with means above 3 points) both the contents provided (IT1) and the adequacy of these contents to the subject (IT2). Students also consider the use of AutoCAD (IT3) as a tool for learning CAD (around 3.7 points in both groups) and the use of PBL (IT5) as a learning methodology for the last practical sessions (3.17 CG vs. 3.24 EG). In summary, all of the common aspects, regarding the proposed strategies

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in both groups, obtained similar evaluations by the students. This is in line with the approach of this experience: isolate the TrainCAD effect to analyse its influence on this experience.

6 | CONCLUSIONS AND LIMITATIONS

The acquisition of CAD skills and knowledge is a key aspect for the proper academic education of an Engineer. For achieving this knowledge, the use of innovative tools and methodologies, that improve and complement the learning-teaching process, is increasingly in demand.

The proposed experience in this article aimed at showing the advantages of integrating an interactive self-assessment tool with the usual learning methodology of CAD (in this case, PBL). Therefore, the modifications conducted in CAD teaching were analysed, with the aim of showing the potential changes in the students' results. It was concluded that these changes clearly improve not only the students' academic performance but also their interest in the subject. Consequently, this type of innovative tools fits very well with the common CAD learning methodologies and their combination boosts the students' abilities and gets the most of the students' study process. Likewise, it was concluded that the gender factor did not have a significant impact on academic performance when integrating the self-assessments tool in the CAD pedagogy.

The innovative self-assessment CAD tool that was presented in this experience aimed at complementing, but not replacing, the already established CAD learning methodology. The technology developed has made it possible to extract significant information from the teaching-learning process of the participating students. This implied that, as there was continuous feedback, the student's response times were significantly optimised. At the same time, an increase in active student participation to learn and develop a better comprehension of the studied contents was noted.

In addition, there are not just advantages for the students, but also for the teachers. Indeed, TrainCAD provides the teacher with the opportunity to monitor and control the students' learning process through its web monitoring tools. In this way, both the teacher and the student know in real time the current learning status of the student and their acquired and in-progress CAD competences, as well as the aspects that needs to be reinforced due to the difficulties arising during the learning process. Moreover, the teacher's time reduction to review the students' exercises provides an additional stimulus to the teacher, who can focus their effort in guiding the students' learning process and pinpoint the aspects that need further dedication.

Other implications of the integration of the self-assessment tools on the traditional CAD learning methodology are: an enrichment of the employed learning resources, a reduction of the subject dropout rate and the use of the designed content as a fluid and complete mechanism of CAD knowledge acquisition. The statistical analysis of the satisfaction survey results and the students' remarks confirmed the high level of satisfaction among the students of EG, concerning the innovative tools described in this article.

Although PBL has been used in this experience, TrainCAD was not only designed to be used with this methodology. Therefore, future work could analyse the possibility of integrating this type of application within other methodologies whose goal is CAD learning. Likewise, TrainCAD could be updated and applied in other areas, such as 3D models, in line with those described by Pando Cerra et al. [51]. From the results obtained from the experience and the feedback received by the students, one can also conclude that the proposed learning model could be adjusted to any special situation, such as in-person, blended or online learning and to other situations where CAD may be needed to solve problems.

Regarding the limitations of this study, it can be indicated that this study has mainly been focused on the students' academic performance. However, other important elements in CAD pedagogy, such as motivation to learn, have not been assessed. Likewise, the study of the gender factor was also focused on academic performance, but this condition was not analysed, either in the prior knowledge test or in the evaluation survey. Future works should explore these aspects as well. In addition, although some teamwork activities have been carried out during this experience, this article only analysed individual learning indicators. Therefore, it could also be interesting to carry out new research on how collaborative activities affect the learning strategies studied in this article. Finally, it was not possible to analyse the relationship between prior CAD knowledge and the obtained achievement results since the initial test was anonymous. This will be analysed in future work.

AUTHOR CONTRIBUTIONS

All authors contributed equally to this study. All authors have read and approved the final manuscript.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

DATA AVAILABILITY STATEMENT

The datasets generated during and/or analysed during the current study are available from the corresponding author on reasonable request. The code generated during the current study is available from the corresponding author on reasonable request.

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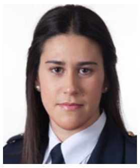

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APPENDIX A: PRIOR KNOWLEDGE TEST

No.	Question	Option 1	Option 2	Option 3	Option 4
I1	How many procedures are available for drawing a circle?	1	More than 3	3	None
I2	Which of the following options are not an AutoCAD coordinate system?	Relatives	Polars	Cartesians	Orthogonals
I3	Which is not a file extension for a CAD programme?	DXF	DWG	GIF	IGES
I4	Which of these references do not exists in AutoCAD?	Curve	Intersection	Quadrant	Extension
I5	Which menu the split tool appears in?	Modify	Draw	Tools	Annotate
I6	Which is not a layer property?	Level	Lock	Lineweight	Colour
I7	Which is the key for activating the ortho mode?	F2	F5	F8	F4
I8	Which is not an available zoom option?	Window	Dynamic	All	Quick
I9	The arc is drawed:	Clockwise	Counter-clockwise	Both	None
I10	To draw a line 20 cm to the right you have to type:	20,0	@20,0	@20,20	@20 < 180
I11	Which is the complete functionality for the ESC key:	Cancel all the commands	Cancel the line mode	Cancel only selected entities	Cancel commands and selected entities
I12	Is it needed to define a base point for a block insertion?	Yes	No	It is optional	Only in the Dynamic blocks.
I13	The character combination to generate the diameter symbol with TEXT commands is:	%%g	%%c	%%d	%%s
I14	A polyline comprises:	Only lines	Only arcs	Lines and arcs	Lines and circumferences
I15	The key that allows to change the isoplane is:	F5	F2	F8	F3
I16	Does the command TAN TAN TAN need a radius?	Yes	No	This command does not exist.	It is optional

(Continues)

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No.	Question	Option 1	Option 2	Option 3	Option 4
I17	Which of the following commands is not a shadowing pattern?	SOLID	HEXAGONAL	STARS	ANSI31
I18	Which is the symbol required by the polar coordinates?	>	#	<	@
I19	Which menu the COPY order belong to?	Draw	Properties	Annotate	Modify
I20	Which is not a dim type?	Angular	Radial	Parallel	Linear

APPENDIX B: SATISFACTION SURVEY

ID	Item
IT1	The studied contents are suitable.
IT2	The provided materials ease the learning process.
IT3	AutoCAD is useful for CAD learning.
IT4	The solving exercise method facilitated the CAD learning tools.
IT5	PBL improved the learning process.
IT6	The required time demanded during the subject learning process is suitable.
IT7	Throughout the solving exercises phase, the response time was suitable.
IT8	The assessment method for the subject is suitable.
IT9	The learning experience successfully fulfilled with your expectations and needs.

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