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Análisis de las competencias de razonamiento mecánico y las relaciones espaciales en estudiantes universitarios de la carrera de diseño industrial

Analysis of mechanical reasoning competencies and spatial relationships in undergraduate students of the industrial design career

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Palabras claves:
Razonamiento Mecánico; Relaciones Espaciales; TAD, Diseño Industrial.

Resumen

Introducción. El campo del Diseño Industrial requiere una amplia gama de habilidades, entre las que destacan el razonamiento mecánico y las relaciones espaciales. El razonamiento mecánico implica entender los elementos y su interacción en sistemas mecánicos, mientras que las relaciones espaciales involucran la capacidad de visualizar y manipular objetos en el espacio. Estas competencias son esenciales para concebir y comunicar ideas de diseño efectivas. La investigación emplea el Test de Aptitudes Diferenciales TAD-5 para identificar áreas de mejora en estas habilidades y proponer estrategias pedagógicas para fortalecerlas en el currículo de Diseño Industrial. Mejorar estas competencias no solo beneficiará a los estudiantes en el abordaje de desafíos de diseño, sino que también contribuirá al crecimiento y excelencia del campo. **Objetivo.** Evaluar y el nivel de desarrollo de las competencias de Razonamiento Mecánico y Relaciones Espaciales en estudiantes de Diseño Industrial, utilizando el Test de Aptitudes Diferenciales TAD-5. **Metodología.** El estudio adopta un enfoque cuantitativo, centrado en la cuantificación de datos recopilados, pero reconoce la necesidad de comprender completamente el fenómeno investigado. Se emplean técnicas de recopilación y análisis de datos numéricos, como estadísticas descriptivas e inferenciales, junto con instrumentos como cuestionarios o pruebas con respuestas numéricas o en escalas de medición. Aunque se privilegia el análisis cuantitativo, para proporcionar un contexto más completo y comprender las experiencias y percepciones de los participantes. La población de estudio comprende 49 alumnos, divididos en 32 estudiantes de primer semestre y 17 estudiantes de octavo semestre, lo que representa tanto el inicio como el final de su formación académica en el contexto del Diseño Industrial. **Resultados.** El propósito de la evaluación realizada en el primer y último semestre de la Carrera de Diseño Industrial es determinar si los estudiantes han adquirido un conjunto mayor de habilidades y destrezas durante su trayectoria académica. Aunque los resultados muestran un desempeño superior en los estudiantes de octavo semestre en comparación con los de primer semestre, la diferencia no es significativa, indicando un avance limitado en el desarrollo de habilidades durante la formación. Se proponen acciones de mejora, incluyendo la repetición de la prueba con un nuevo cuestionario, la participación de más docentes para un mejor control y ejecución de la prueba, y la mejora del entorno y la calidad de las imágenes utilizadas. Se planea elaborar un plan para fomentar el desarrollo de habilidades en futuros Ingenieros en Diseño Industrial, con acciones a corto, mediano y largo plazo que incluyen la identificación de cursos externos, la revisión de contenidos mínimos de asignaturas y modificaciones en el plan de estudios para adaptarlo a las demandas profesionales actuales. **Conclusión.** El estudio resalta la importancia crítica de las competencias de Razonamiento Mecánico y Relaciones Espaciales en el Diseño Industrial, esenciales para la conceptualización, creación y comunicación efectiva de ideas de diseño. La utilización del Test de Aptitudes Diferenciales TAD-5 demostró ser valiosa para evaluar estas competencias en los estudiantes, revelando que no hay una diferencia significativa entre los niveles de competencia de los estudiantes de primer y octavo semestre. Aunque los niveles de competencia son similares, se identifican deficiencias en el Razonamiento Mecánico, indicando la necesidad de ajustes en el contenido curricular y las estrategias pedagógicas del programa de Diseño Industrial para fortalecer estas habilidades mediante enfoques de enseñanza específicos y prácticos. **Área de estudio general:** Diseño Industrial. **Área de estudio específica:** Dibujo técnico

Keywords: Mechanical Reasoning; Spatial relations; TAD, Industrial Design.

Abstract

Introduction. The field of Industrial Design requires a wide range of skills, among which mechanical reasoning and spatial relationships stand out. Mechanical reasoning involves understanding the elements and their interaction in mechanical systems, while spatial relationships involve the ability to visualize and manipulate objects in space. These competencies are essential for conceiving and communicating effective design ideas. The research employs the TAD-5 Differential Aptitude Test to identify areas of improvement in these skills and propose pedagogical strategies to strengthen them in the Industrial Design curriculum. Improving these competencies will not only benefit students in addressing design challenges, but will also contribute to the growth and excellence of the field. objective. To evaluate and the level of development of the competencies of Mechanical Reasoning and Spatial Relationships in Industrial Design students, using the Differential Aptitude Test TAD-5. Methodology. The study adopts a quantitative approach, focused on the quantification of collected data, but recognizes the need to fully understand the investigated phenomenon. Numerical data collection and analysis techniques are employed, such as descriptive and inferential statistics, together with instruments such as questionnaires or tests with numerical responses or measurement scales. Although quantitative analysis is privileged, in order to provide a more complete context and to understand the experiences and perceptions of the participants. The study population comprises 49 students, divided into 32 first semester students and 17 eighth semester students, representing both the beginning and the end of their academic training in the context of Industrial Design. Results. The purpose of the evaluation conducted in the first and last semester of the Industrial Design Career is to determine whether students have acquired a greater set of skills and abilities during their academic career. Although the results show a superior performance in eighth semester students compared to first semester students, the difference is not significant, indicating limited progress in the development of skills during training. Improvement actions are proposed, including repeating the test with a new questionnaire, involving more teachers for better control and execution of the test, and improving the environment and quality of the images used. It is planned to elaborate a plan to foster the development of skills in future Industrial Design Engineers, with short, medium and long term actions that include the identification of external courses, the review of minimum contents of subjects and modifications in the curriculum to adapt it to the current professional demands. Conclusion. The study highlights the critical importance of the competencies of Mechanical Reasoning and Spatial Relationships in Industrial Design, essential for the conceptualization,creation and effective communication of design ideas. The use of the TAD-5 Differential Aptitude Test proved valuable in assessing these competencies in students, revealing that there is no significant difference between the competency levels of first and eighth semester students. Although the proficiency levels are similar, deficiencies are identified in Mechanical Reasoning, indicating the need for adjustments in the curricular content and pedagogical strategies of the Industrial Design program to strengthen these skills through specific and practical teaching approaches. General area of study: Industrial Design. Specific Area of Study: Technical Drawing

Introduction

The field of Industrial Design is a fertile ground for creativity and innovation, where professionals must possess a wide range of skills to conceive, shape and materialize their ideas into functional and aesthetically appealing products. Among these skills, two aspects stand out for their crucial relevance: mechanical reasoning and spatial relationships. These competencies are fundamental to enable Industrial Design students to conceptualize, create and communicate their design ideas effectively.

Mechanical reasoning refers to a high-level cognitive process by which a person can recognize the fundamental elements of a mechanical system and understand their importance in its operation, as well as infer how they interact with each other. Mechanical reasoning (MR) refers to the ability to recognize the elements of a system and understand how they interact with each other so that the system can operate (Injoque-Ricle et al, 2019). The authors' arguments about mechanical reasoning, working memory and processing speed. Mechanical learning is also defined by its methodical approach and high retention of facts, in their study on cognitive strategies for meaningful learning in students of three Civil Engineering degrees at the University of Bío-Bío (Sanchez et al, 2015).

Injoque-Ricle, (2019) define mechanical reasoning (MR) as the ability to recognize the elements of a system and understand their interactions essential to the functioning of the system. Mechanical reasoning involves the ability to understand the fundamental principles of mechanics and physics, allowing designers to make informed decisions about the structure and operation of the products they design.

On the other hand, spatial relations or perception involve the ability to visualize and manipulate three-dimensional objects in space, which is essential for designing products that fit the needs and expectations of users. Visualization, which is defined as the ability to modify, rotate, deform or change the orientation of mental representations of objects, constitutes the preponderant factor in spatial skills. Perception is defined as a cognitive process that has the ability to actively acquire, analyze and attribute meaning to the information that our senses receive (Freré Arauz et al, 2021).

Understanding spatial and complex structures can be challenging, especially when faced with deformations under different loading situations or other external stimuli. This becomes even more complicated for some people. (Nolasco, 2020).

To carry out this evaluation, we have used the TAD-5 Differential Aptitudes Test, the authors George K. Bennet, Harold G. Seashore and Alexander G. Wesman were the original creators of this test, which was conceived in 1967 in the United States. Its main objective was to provide a properly standardized scientific tool to evaluate students' aptitudes; later, this test was adapted for the second time in Spain, in 1999, under the supervision of the Madrid Test Section (TEA) (Cortez CV (2022)and (Ghio et al, 2022). It is a specialized tool designed to accurately measure mechanical skills and spatial relationships. The purpose of this research is to identify areas for improvement in these skills and to propose specific pedagogical strategies to strengthen them in the academic curriculum of the Industrial Design degree.

The outcome of this research will not only benefit students by improving their ability to address design challenges more effectively, but will also contribute to the growth and excellence of the Industrial Design field by training highly competent professionals prepared to face the challenges of the industry. Throughout this study, we will carefully explore the results obtained and their implication in the training of future Industrial Design engineers.

Materials and methods

Huanca et al, (2023). Qualitative research requires us to recognize a variety of different contexts in order to understand the multiple perspectives of the phenomenon we are investigating. To achieve this, it is not enough to use a single method; rather, it is necessary to combine several methods along with their respective tools and instruments, taking into account both their advantages and limitations taken from (Piza Burgos et al, 2019).

This is because it refers to the collection and analysis of numerical data, the application of descriptive and inferential statistics, and the presentation of results in terms of figures and percentages. In addition, it refers to the use of a questionnaire or test with numerical responses or measurement scales.

However, it is important to note that at some stages of the research, such as the interpretation of results, it is possible to combine qualitative elements to provide a more complete context or to understand the experiences and perceptions of participants. The qualitative approach focuses on understanding subjective meanings and apprehending the context in which the phenomenon develops (Ortega et al, 2023). This will allow a more complete understanding of the competencies studied by considering both quantitative data and qualitative aspects.

The population refers to the entire group of people who share common observable characteristics in a specific place and time, and it is in this context that the research will be carried out. (Moreno, 2021). As a case study, it includes a total of 49 students, 32 students in their first semester, representing the beginning of their academic training, and 17 students in their eighth semester, symbolizing the end point of their academic training path.

Table 1.

Student data

Objective of study	Number	Semester	Percentage
Students	32	First	65.31%
Students	17	Eighth	34.69%
Total	49		100%

Fountain: Student information. FDA-UTA
Prepared by: Walls; Monar; Heredia; Gutierrez

For this research, a deliberate non-random sampling method was used. This involved subdividing the population into smaller groups that shared internal similarities in relation to the characteristics of interest in the research.

Procedure

González et al, (2023) the research requires the development of two multiple choice questionnaires as data collection instruments. The first was administered at the beginning of the session, while the second was carried out at the end, after completing the activities with the 3D manufactured parts. This initiative aims to address deficiencies in the understanding of geometric problems and visual reasoning. The skills that students acquire in this context will not only be significant in improving academic performance in subjects related to graphic expression.

Once the Design Aptitude Test (DAT-5), Level 1, was chosen, the nature of the evaluation was analyzed and understood. This test assesses skills in various areas, standing out for its ability to assess skill groups in a specific way. It is possible to measure skills in verbal, numerical, abstract, mechanical, spatial reasoning, spelling, and perceptual speed and accuracy. The advantage of this lies in its flexibility, since it is not necessary to administer the test in its entirety to obtain an evaluation of the student's performance. The Differential Aptitude tests have been designed with the objective of measuring the ability of students to learn or perform efficiently in particular areas and also in professionals. (León et al, 2022) and (Condori, 2023).

When examining the curricular structure of the Industrial Design Degree, areas of special relevance in terms of skills were identified, such as technical drawing, modeling I and II, as well as subjects related to physics, industrial chemistry, calculus, mathematics, materials and processes. Considering this academic load and the importance of spatial intelligence, it was determined that the mechanical reasoning test is especially pertinent to assess the skills acquired by students throughout their training. However, the need to assess numerical and abstract reasoning skills in the training of future professionals in industrial design and engineering was also recognized.

In this context, it was decided to carry out a first survey with two groups of tests: mechanical reasoning and spatial reasoning. Mechanical reasoning consists of 60 questions, designed to be answered in no more than 30 minutes. The questions do not involve complex calculations or intricate mechanical systems, but rather focus on evaluating the logical understanding of basic mechanisms and fundamental concepts of physics and mechanics. On the other hand, spatial reasoning has a section with 50 questions, intended to be answered in no more than 25 minutes. This section seeks to evaluate the ability to visualize and manipulate flat figures mentally, rotating them according to the options provided in each question. It is important to highlight that this instrument does not require normative knowledge, scale or tools for its resolution, but rather focuses on the development of spatial intelligence when interpreting the representation of figures in different positions.

It is worth noting that this instrument is versatile in its application, being suitable for high school students, university students, and even for job interviews where specific skills related to the position need to be assessed. The assessment was carried out following the instructions of the test, starting with the mechanical component, followed by a brief 5-minute rest period, and then the administration of the spatial reasoning component.

The information collected was then tabulated and percentage scores were calculated, considering that the mechanical reasoning section consists of 60 questions, while the spatial reasoning section has 50 questions. In addition, essential statistical values were determined, such as the average, median, maximum and minimum. These data provided an overall view of the students' performance in the assessments. The average allowed the identification of the general performance of the assessed courses, while the maximum and minimum helped to determine the academic level of the student with the highest score and the level at which a student had the greatest difficulties in solving these skills, respectively.

Table 2.

Grades of students assessed by level.

8th		1st	
Mechanic	Space	Mechanic	Space
46%	68%	46%	60%
46%	88%	64%	70%
36%	70%	38%	55%
78%	53%	48%	43%

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70%	83%	54%	50%
30%	38%	26%	15%
26%	48%	40%	70%
36%	63%	30%	63%
60%	70%	36%	50%
60%	78%	34%	48%
44%	53%	46%	65%
46%	55%	42%	53%
40%	58%	48%	73%
56%	60%	24%	60%
52%	58%	52%	68%
38%	78%	26%	50%
56%	63%	36%	63%
		46%	68%
		64%	40%
		66%	68%
		64%	85%
		58%	60%
		30%	45%
		74%	68%
		62%	90%
		36%	40%
		42%	83%
		68%	78%
		46%	73%
		60%	60%
		58%	65%
		48%	58%

Fountain: Student information. FDA-UTA
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Table 3.

Statistical calculations of the grades evaluated.

	8th semester		1st semester	
	Mechanic	Space	Mechanic	Space
Average	48%	63%	47%	60%
Average	46%	63%	46%	61%
Maximum	78%	88%	74%	90%
Minimum	26%	38%	24%	15%

Fountain: Student information. FDA-UTA

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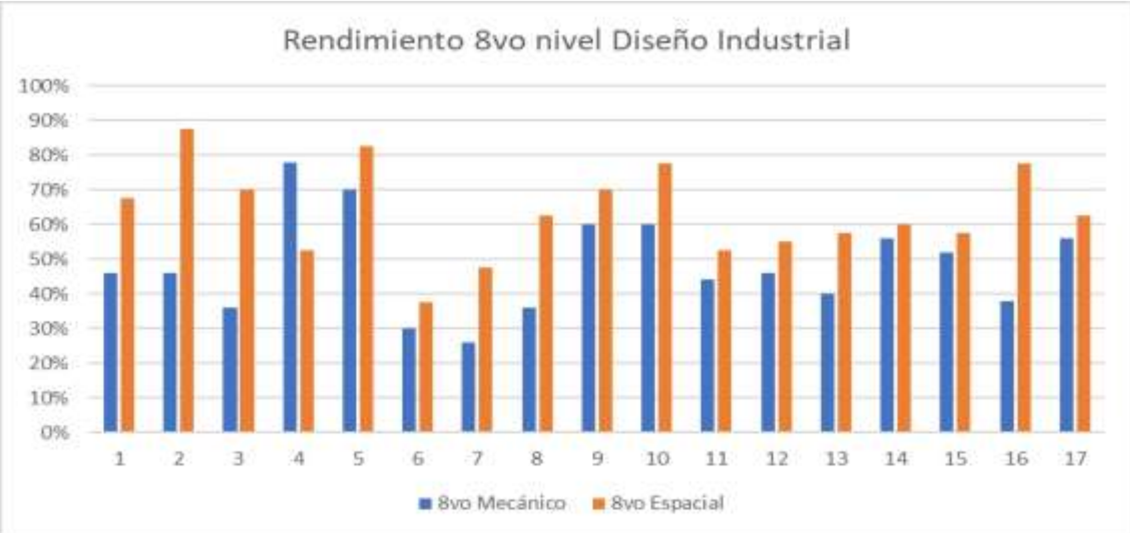
Tables 2 and 3 present the data expressed in percentages corresponding to the evaluations carried out, including relevant statistical information such as average, median, maximum value and minimum value.

Chart 1.

Evaluation of eighth semester Industrial Design students.



Fountain: Student information. FDA-UTA
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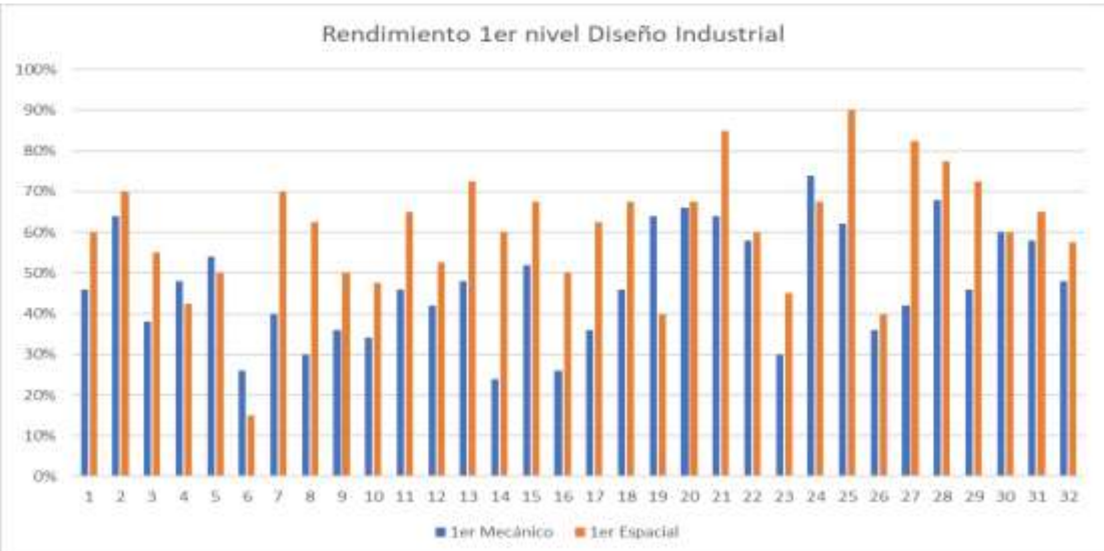
Chart 2.

Evaluation of First Semester Industrial Design students.



Fountain: Student information. FDA-UTA
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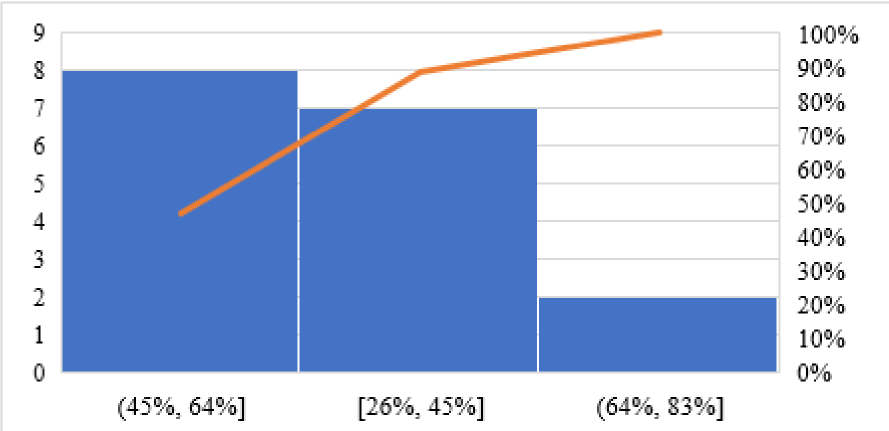
Figures 1 and 2 visually illustrate student performance, with mechanical ability in blue and spatial ability in orange. The "y" axis specifies the grade percentage and the "x" axis the number of students evaluated by level. Each bar represents the performance of a specific student in these areas. To preserve confidentiality, student names have been replaced by identifying numbers, thus ensuring the anonymity of the participants in this study.

Chart 3.

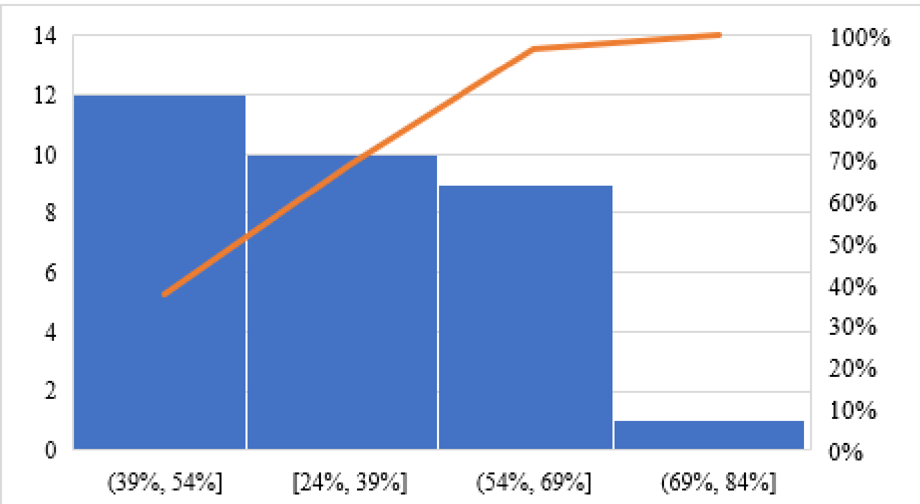
Grade trends for eighth semester students, Industrial Design.



Fountain: Student information. FDA-UTA
Prepared by: Walls; Monar; Heredia; Gutierrez

Chart 4.

Trends in first semester student grades, Industrial Design



Fountain: Student information. FDA-UTA
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There is a clear difference in performance between students in general and students who excel in mechanical and spatial skills. Figure 3 shows that 45% of students have obtained an average score in mechanical skills, while 64% have achieved a similar score in spatial skills. This suggests that most students have a moderate performance in these areas.

On the other hand, when considering the best students, it is observed that only 2 students achieved higher scores, with 64% and 83% in mechanical and spatial ability respectively. This suggests that only a small percentage of students have demonstrated outstanding mastery in these specific skills.

In Figure 4, it is shown that most students in the initial level of the Degree show average performance, with an average of 39% in the mechanical skill and 54% in the spatial skill. However, one student in particular has managed to outperform even the eighth semester students, with a score of 69% and 84% in both skills, respectively. This indicates exceptional potential in that particular student, outperforming even the most experienced students.

Analysis and discussion of results

The purpose of the assessment carried out in the first and last semester of the Industrial Design Degree is to determine, through a skills test, whether students have acquired a greater set of skills and abilities during their academic career. The application of a comprehensive assessment is suggested, since, although not all skills are perfectly aligned with the specific professional profile of the students, they constitute essential complementary skills that all professionals in any discipline must develop at different levels.

The results show that eighth-semester students have, on average, a higher performance compared to first-semester students; this difference is not significant, with a gap of only 2 percentage points. These 2 points do not demonstrate a substantial advance in the development of the aforementioned skills during academic training.

A color code was implemented, as shown in Table 2, to distinguish student performance in the assessment. Green was used to represent grades equal to or higher than 70%, orange for grades between 40% and 69%, considered unsatisfactory performance, and red for grades below 40%. In the case of mechanical ability, an average higher than 50% was not achieved at either level. This skill could be developed during the training of first-semester students, but the same level of development is not observed in final-semester students.

As a research team, we propose improvement actions that include repeating the test with a new questionnaire and the participation of more teachers to ensure adequate time control and optimal execution of the test. In addition, we propose improving the environment where the evaluation was administered and the quality of the images used in the test. Once the evaluation has been carried out at each level of the Industrial Design Degree, we intend to develop a plan that encourages the development of skills in future "Industrial Design Engineers".

In terms of short-term actions for levels close to graduation, the identification of external courses that strengthen essential skills for a professional environment is contemplated. In the intermediate term, it is planned to review the minimum content of the contributory subjects and evaluate whether they are being taught in accordance with the curriculum and teacher evaluations. In the long term, the aim is to determine modifications to the curriculum to adapt the professional profile of the Industrial Design Degree of the Faculty of Design and Architecture of the Technical University of Ambato. This approach seeks to guarantee training in accordance with the demands and trends of the professional field.

Conclusions

- The study confirms the critical importance of Mechanical Reasoning and Spatial Relations competencies in the field of Industrial Design. These skills are fundamental for students to effectively conceptualize, create and communicate their product design ideas.
- The use of the TAD-5 Differential Aptitudes Test proved to be a useful tool for assessing mechanical and spatial skills in students. This provides an objective basis for measuring these skills.
- The results reveal that there is no significant difference in the competencies between first semester (initial) and eighth semester (final) students of the Industrial Design Degree. The average difference in percentages was 2%, suggesting that the training does not achieve a substantial increase in these competencies throughout the degree.
- Despite the similarity in the levels of competence, the results show that there are deficiencies in the Mechanical Reasoning competencies, with a percentage of 47%. This indicates that there is room for improvement in the training of students in this specific aspect.
- The identified deficiencies in mechanical reasoning indicate that the Industrial Design program could benefit from adjustments in curricular content and pedagogical strategies. It is essential to develop specific teaching methods that help strengthen students' mechanical reasoning skills, such as practical problem solving and projects that foster a deeper understanding of mechanical principles.

Conflict of interest

The authors declare that they have no conflict of interest.

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