

Functionality and Efficiency of AI-Based Learning through Design Thinking in Engineering Disciplines: An Empirical Analysis

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Abstract: - This study examines the functionality and efficiency of AI-based learning implemented through the design thinking method within the context of engineering disciplines. In the wake of increasing digitalization and the integration of artificial intelligence in education, there is a growing need to evaluate the impact of such pedagogical models on the educational process and student development. The empirical study was conducted over two academic years among 64 engineering students, organized into teams and engaged in developing cyber-physical systems to solve real-world problems. The evaluation is based on four key areas: educational efficiency, creativity and design thinking, technological functionality, and educational experience and student impact. Data were collected through exploratory observation and analyzed using a system of indicators with a quantitative scale. The results of the study confirm that the integration of AI and design thinking creates an effective educational environment that supports the development of key engineering competencies and fosters active, engaged, and practice-oriented learning.

Key-Words: - AI-based learning, cyber-physical systems, design thinking, pedagogical models, quantitative evaluation, artificial intelligence in education, student engagement, engineering education.

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1 Introduction

The rapid development of digital technologies and the integration of artificial intelligence (AI) into education present new demands for engineering training. Modern engineers must not only possess deep technical knowledge but also demonstrate critical thinking, creativity, and the ability to effectively resolve complex problems. In this context, traditional teaching approaches prove insufficient [1], [2] for developing competencies that align with today’s technological environment. The integration of AI-based tools into learning creates opportunities to personalize the educational process, automate feedback, and support analytical thinking, [3]. In parallel, the design thinking method has established itself as an effective pedagogical approach oriented toward solving real-world problems through empathy, ideation, prototyping,

and testing. By combining the technological potential of artificial intelligence with the process-driven logic of design thinking, an innovative learning model is developed to foster active and engaged student participation.

Despite growing interest in using AI in education, there remains a clear need for empirical research to evaluate the effectiveness of such integrated approaches, particularly in engineering disciplines. A limited number of studies simultaneously examine the impact on learning outcomes, creativity, technological adaptation, and the overall educational experience of students.

This paper aims to investigate the effectiveness of AI-based learning through design thinking in engineering disciplines by analyzing its impact on key aspects of the educational process. The focus is placed on an empirical study encompassing

educational efficiency, the development of creativity and design thinking, technological functionality, and the impact on the student experience. This study aims to expand scientific knowledge on the application of AI in engineering education and to outline guidelines for more effective integration of innovative pedagogical approaches into the learning process, [4], [5].

2 Integrating AI and Design Thinking in Engineering Education

The integration of AI technologies into engineering education is redefining how students acquire knowledge, analyze data, and develop technical solutions. AI-driven tools offer capabilities for automated feedback, ideation, data processing, simulation, and computer-aided design, thereby significantly expanding the range of traditional instructional methods. Within engineering disciplines, this accelerates analytical processes and shifts the pedagogical focus toward practical application and real-world problem-solving.

A major advantage of AI-based learning environments is their capacity to adapt to individual student needs. Through intelligent learning analytics systems, educational platforms can identify knowledge gaps, provide personalized guidance, and facilitate self-paced learning. This is particularly critical in engineering education, where students frequently encounter complex concepts, algorithms, and technological interdependencies that demand varying levels of scaffolding and supplementary practice, a phenomenon that has been shown to significantly improve overall student outcomes, [6].

Concurrently, AI tools enable more dynamic visualization and simulation of engineering processes. Utilizing intelligent platforms, students can model systems, test diverse parameters, analyze errors, and optimize their designs in real time. This fosters systemic and analytical thinking while reducing the time required for routine technical tasks, allowing students to focus on the conceptual and design phases of engineering work.

In parallel, the Design Thinking methodology offers a pedagogical framework

centered on user needs, iterative experimentation, and the generation of innovative solutions. The core stages of the method—empathize, define, ideate, prototype, and test—cultivate an environment for active learning, collaborative teamwork, and the development of creative engineering intuition. In the context of engineering education, this approach encourages students not only to engineer functional technical solutions but also to account for the constraints of real-world environments and the requirements of end-users.

A particularly significant aspect of Design Thinking is its orientation toward solving authentic, practical problems. Unlike traditional educational models based primarily on passive theoretical knowledge acquisition, this approach places students in scenarios requiring active discovery, synthesis, and solution validation. Consequently, the educational experience closely mirrors contemporary engineering practice, where developing efficient systems demands a combination of technical proficiency, creativity, adaptability, and teamwork.

The convergence of AI and Design Thinking yields an integrated educational model wherein technological tools support the distinct phases of project-based work, [7], [8]. AI platforms can be leveraged for problem space analysis, ideation and evaluation, solution modeling, programming, visualization, and prototype optimization. As a result, students are empowered to experiment with diverse engineering approaches, validate their hypotheses, and iteratively refine their projects in real time.

Also, the integration of AI and Design Thinking fosters an interdisciplinary approach to engineering education. When developing engineering projects, students must synthesize knowledge across multiple domains, including programming, electronics, automation, data analytics, user interaction, and process management. AI tools streamline data processing and knowledge synthesis, while Design Thinking provides the procedural

framework required to organize workflows and structure solutions.

An additional benefit of this model is its potential to increase student motivation and engagement. Contemporary students operate within an ecosystem of ubiquitous digital communication and perceive technology as an intuitive element of their daily lives. Incorporating AI platforms into the curriculum introduces a sense of relevance, practical utility, and alignment with the professional technological environments they will soon enter. This shifts student behavior toward greater autonomy, proactivity, and active participation in the learning process.

A key aspect of this integrated model is the cultivation of skills necessary to critically evaluate information and outputs generated by AI systems. Although AI tools significantly enhance engineering workflows, they do not replace the necessity for human judgment, logical reasoning, and professional accountability. Design Thinking serves an essential function here, as it inherently encourages rigorous analysis, reflection, verification, and the continuous refinement of solutions.

This model also changes the roles of the stakeholders within the educational ecosystem. The instructor transitions from the primary source of information to a facilitator and architect of the learning environment, while students shift from passive consumers to active constructors of knowledge. Education becomes oriented toward independent inquiry, collaborative execution, and the practical application of theory, matching contemporary benchmarks for engineering competencies. In engineering disciplines, this paradigm is uniquely fitting, as it bridges technical precision, systems thinking, and innovation. Integrating AI within a Design Thinking framework enables a dynamic, adaptive educational environment tailored to developing the competencies required in a digital, technology-intensive economy, [9], [10]. Concurrently, this synthesis prepares future engineers not only to utilize emerging

technologies but also to critically appraise their applications, design sustainable solutions, and adapt to an evolving technological landscape.

3 Research methodology

The subject of this empirical study is the functionality and pedagogical effectiveness of the Design Thinking methodology within an AI-based environment in engineering education. The evaluation is structured across four primary domains: educational effectiveness, creativity and design thinking, technological functionality, and educational experience and student impact.

- The "Educational Effectiveness" domain encompasses the degree of knowledge acquisition, skills, and competencies achieved by students through the Design Thinking method integrated with AI-supported instruction in engineering disciplines.
- The "Creativity and Design Thinking" domain focuses on the successful application of the Design Thinking methodology, the generation of non-traditional ideas, and the formulation of creative solutions.
- The "Technological Functionality" domain examines the reliability, integration, and adaptability of the AI tools utilized within the instructional process.
- The "Educational Experience and Student Impact" domain assesses the emotional, cognitive, and motivational aspects of participating in these technology-assisted learning activities.

The empirical study was conducted using the observational research method. For this purpose, specific observation indicators were developed, as presented in Table 1.

Table 1. Observation indicators across evaluation domains

Evaluation Domain	Indicators
<i>Educational Effectiveness</i>	Acquisition and transfer of engineering knowledge within the context of design thinking and AI
	Development of engineering concepts through the application of core engineering principles in

	conjunction with AI tools and applications
	Systems thinking and analytical approach in the development of integrated engineering solutions incorporating AI technologies
	Development of key engineering skills—planning, modeling, data analysis, optimization, and communication—through the application of AI for analysis and simulation
	Effective application of AI tools in solving engineering tasks
<i>Technological Functionality</i>	Synergistic combination of AI tools and technologies for the development of complex engineering solutions
	Creative utilization of AI functionalities
	Interpretation and critical evaluation of AI-generated results
	Understanding user needs and demonstrating empathy within the engineering context
<i>Creativity and Design Thinking</i>	Formulation of engineering problems through the principles of design thinking
	Generation of creative engineering ideas and original solutions in synergy with AI tools
	Creation of innovative engineering concepts and prototypes utilizing AI for modeling and simulation
	Depth of thought and active engagement in problem-oriented tasks
<i>Educational Experience and Student Impact</i>	Positive attitude, interest, and satisfaction with the learning process
	Engagement and motivation in utilizing AI
	Effective teamwork and collaboration

Source: created by the authors.

Four indicators were formulated for each evaluated domain. Because the study comprehensively analyses knowledge, technological integration, creativity, and emotional engagement, all four domains are weighted equally. Within each respective domains; the weight is evenly distributed among the corresponding indicators. Each indicator is evaluated on a scale from 0 to 6 points, depending on the degree of manifestation:

- Strongly manifested: 6 points
- Moderately manifested: 4–5 points
- Weakly manifested: 2–3 points
- Not manifested: 0–1 points

The sum of the indicator scores for each domain determines its final score (minimum 0, maximum 24 points). To interpret these results, a five-level effectiveness evaluation scale was established, as shown in Table 2. The scale includes the following performance tiers: high, very good, good, fair, and poor effectiveness. The performance level for each domain is determined by the total score in the 0–24 range.

Table 2. Effectiveness evaluation scale based on total domain scores

Performance Levels	Score Range (Points)
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High	21–24
Very Good	16–20
Good	11–15
Fair	6–10
Poor	0–5

Source: created by the authors.

The pilot implementation was conducted within the course Parametric and generative design; Software packages for 3D modelling of cyber-physical systems with 64 undergraduate students (across their 2nd, 3rd, and 4th years) enrolled in engineering majors over the course of two academic years. For this purpose, student teams were formed and tasked with developing course projects on the topic of "Cyber-Physical Systems." These projects were required to address current problems within a specific environment and target audience selected by each respective team.

In the development of engineering projects and cyber-physical systems, the role of AI is significant because it requires combining analytical thinking, programming, modelling, and the integration of diverse technological components. AI tools assist students with simulations, error diagnostics, code generation, and the evaluation of alternative optimization variants. This establishes the necessary conditions for a deeper understanding of engineering processes and a more effective application of theoretical knowledge in a practical environment.

The project workflows were structured according to the stages of the Design Thinking methodology. Throughout the project development process, the teams were permitted to utilize AI-based platforms tailored to the specific technical requirements of their design.

4 Empirical Research Results

During the execution of the projects, student performance was monitored and evaluated by the instructor based on the predefined indicators. Table 3 summarizes the quantitative results from this empirical study, which are also shown in Figure 1.

Table 3. Distribution of student performance efficiency levels across assessment areas (%)

Evaluation Domain.	Performance Levels, %				
	Poor	Fair	Good	Very Good	High
Educational Effectiveness	2%	5%	12%	39%	42%
Technological	3%	3%	6%	31%	56%

Functionality					
Creativity and Design Thinking	3%	8%	14%	42%	33%
Educational Experience and Student Impact	2%	5%	3%	23%	67%

Source: created by the authors.

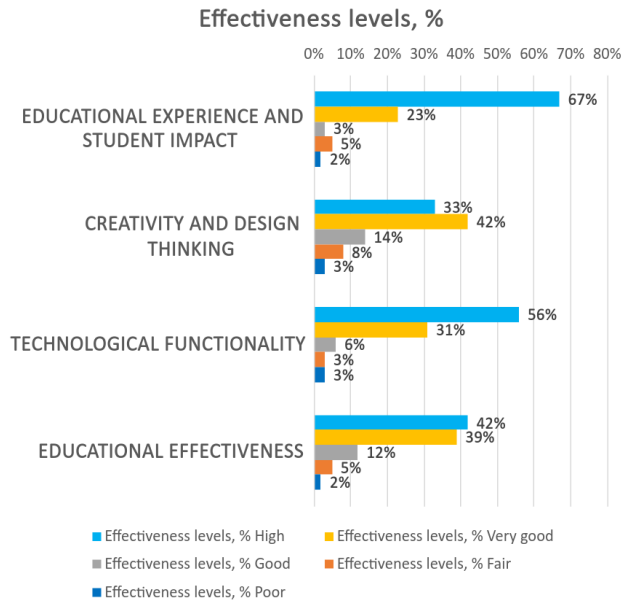


Fig. 1: Comparative analysis of student performance efficiency across evaluation domains

Source: created by the authors.

5 Statistical Data Processing

For the purpose of statistical analysis, the empirical results were evaluated by calculating aggregated performance metrics for each investigated domain. A five-level scale corresponding to the effectiveness levels was utilized: "poor," "fair," "good," "very good," and "high." A numerical value from 1 to 5 was assigned to each level, enabling the calculation of mean indices, variability, and comparative coefficients.

5.1 Mean Effectiveness Index by Domain

For the quantitative aggregation of the results, a mean effectiveness index was calculated for each investigated domain. The index represents a weighted average of the percentage distribution across the five effectiveness levels.

Formula:

$$I_j = \frac{1}{100} \sum_{i=1}^5 (p_{ij} \cdot v_i)$$

where:

- I_j - mean index of the j -th investigated domain;
- p_{ij} - percentage share of students evaluated at the i -th effectiveness level in the j -th investigated domain;
- v_i - numerical value of the i -th level (1-5)

The obtained results are presented in Table 4.

Table 4. Mean effectiveness index across evaluation domains

Domain	Mean Index (1–5)
Educational Effectiveness	4.16
Technological Functionality	4.34
Creativity and Design Thinking	3.94
Educational Experience and Student Impact	4.50

Source: created by the authors.

5.2 Overall Integral Effectiveness Index

By averaging the scores across all examined domains, an overall integral effectiveness index was calculated:

$$I_{total} = \frac{1}{4} \sum_{j=1}^4 I_j$$

$$I_{total} = \frac{4.16 + 4.34 + 3.94 + 4.50}{4} = 4.235 \approx 4.24$$

The calculated value of the integral index,

$I_{total} = 4.24$ out of 5.00, indicates a high overall effectiveness of AI-based instruction integrated with Design Thinking in engineering disciplines.

5.3 High-Effectiveness Coefficient

The high-effectiveness coefficient was determined by summing the relative shares of the "very good" and "high" performance levels. These sums are shown in Table 5.

Table 5. High-effectiveness coefficient across evaluation domains

Domain	High-Effectiveness Coefficient (%)
Educational Effectiveness	81%
Technological Functionality	88%

Creativity and Design Thinking	75%
Educational Experience and Student Impact	91%

Source: created by the authors.

The obtained values of the high effectiveness coefficient (75–91%) indicate a significant share of positive evaluations in the highest performance categories ("very good" and "high"). These results demonstrate a consistently positive perception of the AI-based learning environment across all analyzed domains.

5.4 Low-Effectiveness Coefficient

Table 6 shows the low-effectiveness coefficient which was determined by summing the relative shares of the "poor" and "fair" performance levels.

Table 6. Low-effectiveness coefficient across evaluation domains

Domain	Low-Effectiveness Coefficient (%)
Educational Effectiveness	6%
Technological Functionality	6%
Creativity and Design Thinking	11%
Educational Experience and Student Impact	6%

Source: created by the authors.

The resulting low values indicate minimal difficulties and reflect a relatively smooth adaptation of the students to the AI-driven learning environment.

5.5 Comparative Ranking of the Domains

Based on the mean indices, the domains can be ranked by their degree of effectiveness as follows:

1. Educational Experience and Student Impact – 4.50
2. Technological Functionality – 4.34
3. Educational Effectiveness – 4.16
4. Design Thinking and Creativity – 3.94

5.6 Standard Deviation and Variability

To evaluate the dispersion of the results, the standard deviation was calculated for each domain using Equation (3) and the values are presented in Table 7.

$$s_j = \sqrt{\frac{1}{100} \sum_{i=1}^5 p_{ij} \cdot (v_i - I_j)^2}$$

- (3)
- s_j - standard deviation for the j -th domain;
 - p_{ij} - percentage share (%) of students evaluated at the i -th effectiveness level;
 - v_i - numerical value of the i -th effectiveness level (1–5);
 - I_j - mean effectiveness index for the j -th domain.

Table 7. Standard deviation of effectiveness scores across evaluation domains

Domain	Standard Deviation
Educational Effectiveness	0.92
Technological Functionality	0.96
Creativity and Design Thinking	1.03
Educational Experience and Student Impact	0.88

Source: created by the authors.

5.7 Chi-Square Test of Independence and Effect Size Estimation

To evaluate the statistical significance of differences in the distribution of effectiveness levels across the

four investigated domains, a χ^2 (Chi-square) test of independence was applied. The student frequency distributions were analyzed across the five effectiveness levels (poor, fair, good, very good, and high) within the following domains: Educational Effectiveness, Technological Functionality, Design Thinking and Creativity, and Educational Experience and Impact on Students. The observed frequencies for these domains are presented in Table 8.

- Null Hypothesis (H_0): The distribution of effectiveness levels is identical across all domains.
- Alternative Hypothesis (H_1): There are statistically significant differences among the domains.

Table 8. Observed Frequencies - O_{ij}

Evaluation Domain	Effectiveness Levels, number of students					N
	Poor	Fair	Good	Very Good	High	
Educational Effectiveness	1	3	8	25	27	64
Technological Functionality	2	2	4	20	36	64
Creativity & Design Thinking	2	5	9	27	21	64
Educational Experience &	1	3	2	15	43	64

Student Impact						
Column Totals	6	13	23	87	127	256

Source: created by the authors.

The total number of observations is

$$N = 4 \times 64 = 256$$

The expected frequencies are determined by the formula:

$$E_{ij} = \frac{R_i \cdot C_j}{N} \quad (4)$$

where:

- R_i - row total;
- C_j - column total;
- N - total number of observations.

The values of the expected frequencies are summarized in Table 9.

Table 9. Expected frequency values $-E_{ij}$

Level	Expected Frequency
Poor	1.50
Fair	3.25
Good	5.75
Very Good	21.75
High	31.75

Source: created by the authors.

The formula for χ^2 is:

$$\chi^2 = \sum_{i=1}^r \sum_{j=1}^c \frac{(O_{ij} - E_{ij})^2}{E_{ij}} \quad (5)$$

where:

- r - number of rows (in this study, the number of evaluation domains, $r = 4$);
- c - number of columns (in this study, the number of effectiveness levels, $c = 5$).

After calculating all 20 cells, the obtained value is

$$\chi^2 = 20.72$$

The degrees of freedom are calculated using the formula:

$$df = (r - 1)(c - 1)$$

$$df = (4 - 1)(5 - 1) = 12 \quad (6)$$

At a significance level of $\alpha = 0.05$ and

$df = 12$, the critical value is $\chi^2_{(0.05;12)} = 21.026$.

Since $20.72 < 21.026$, the null hypothesis is not rejected.

Based on the χ^2 -distribution, the p -value is determined using the obtained empirical value of

$\chi^2 = 20.72$ and $df = 12$. The calculated probability of obtaining this or a larger value is

$$p = 0.055$$

To evaluate the effect size, Cramér's V coefficient is calculated. The coefficient is determined using the formula:

$$V = \sqrt{\frac{\chi^2}{N(k - 1)}}$$

$$V = \sqrt{\frac{20.72}{256(4 - 1)}} = 0.164 \quad (7)$$

The effect size, evaluated via Cramér's V

coefficient, is $V = 0.164$, which indicates a weak practical association between the evaluation domain and the distribution of effectiveness levels.

6 Analysis of Results

6.1 Qualitative Analysis of the Results

6.1.1 General Trend

The data clearly delineate a sustained trend toward high effectiveness across all investigated domains.

Within each domain, students achieving the "very good" and "high" levels predominate, while the proportion of lower performance scores remains minimal. This indicates that integrating AI-based technologies with the Design Thinking methodology establishes an effective educational environment that simultaneously supports the acquisition of engineering knowledge, cultivates creativity, and stimulates active student participation in the instructional process. Additionally, a distinct trend toward high technological adaptability and a positive educational experience is observed, demonstrating a strong alignment between the applied pedagogical approaches and the expectations of contemporary students.

6.1.2 Analysis of Results in the "Educational Effectiveness" Domain

In the "Educational Effectiveness" domain, a consistently high level of performance is evident: 42% of students attained a "high" level of effectiveness, and 39% attained a "very good" level. The share of students categorized at the "good" level is relatively constrained, while the "fair" (5%) and "poor" (2%) levels occur only incidentally. These results demonstrate that the implemented model of AI-assisted instruction within a Design Thinking framework creates a favorable environment for acquiring engineering knowledge, developing practical skills, and fostering professional competencies.

The findings suggest that students not only assimilate theoretical content but also successfully apply it within the context of authentic engineering tasks. Project-based work centered on the development of Cyber-Physical Systems creates the necessary conditions for the practical application of knowledge, which fosters a deeper understanding of engineering concepts. Within this framework, AI tools serve as cognitive scaffolding, facilitating access to information, data analysis, and the generation of potential solutions. Consequently, this enables students to allocate more attention to evaluation, design, and decision-making processes rather than focusing exclusively on routine technical activities.

The integration of the Design Thinking methodology, which encourages active student engagement in the learning process, also plays a critical role. By progressing through the iterative stages of empathizing, defining the problem, ideating, prototyping, and testing, learners construct systemic and analytical thinking patterns. This

contributes to more sustainable knowledge retention because the instructional content is directly linked to specific practical situations and real-world problems. Thus, instruction shifts away from the traditional model of passive information reception and becomes a process of active knowledge construction.

The high-performance levels can further be attributed to the personalization capabilities offered by AI-based platforms. Students work at different paces, utilize diverse digital resources, and receive rapid feedback during task execution. This allows the instructional process to adapt to individual requirements and supports autonomous learning. Such flexibility is particularly vital in engineering disciplines, where learners frequently vary in their foundational preparation, learning styles, and prior technological experience.

The presence of a small percentage of students at the "fair" and "poor" effectiveness levels indicates that, despite the overall positive outcome, a subset of learners experiences difficulties when integrating engineering knowledge with AI tools and project-based approaches. A plausible explanation is the requirement for a higher degree of autonomy, information management skills, and the capacity to critically select AI-generated content. This suggests a need for supplementary methodological guidance for students who find it more challenging to adapt to dynamic, technology-saturated educational environments.

On the whole, the results confirm that AI-based learning, implemented through the Design Thinking methodology, has substantial potential to enhance educational effectiveness in engineering disciplines. The combination of technological support, project-oriented workflows, and an active student role contributes to building deeper knowledge, practical skills, and a readiness to solve real-world engineering challenges.

6.1.3 Analysis of Results in the "Technological Functionality" Domain

The "Technological Functionality" domain demonstrates some of the highest metrics in this study. Over half of the students (56%) achieved a "high" level of effectiveness, with an additional 31% evaluated at a "very good" level. The proportion of students at a "good" level is significantly lower (6%), while "fair" and "poor" levels are observed in only 3% of the participants. These results demonstrate a high degree of technological adaptability and the successful

integration of AI tools as an intuitive, natural component of the instructional process.

The high values in this domain can be explained by several interrelated factors. First, contemporary students belong to a generation that operates in a digital environment daily and demonstrates a high degree of technological adaptability. Working with online platforms, intelligent applications, and automated systems is a natural element of their communication, education, and social activity. This substantially reduces barriers to integrating AI tools into the educational process, shifting the primary focus away from mastering the technology itself and toward applying it to solve engineering problems.

The nature of the utilized AI tools is another significant factor contributing to these high results. Generative AI platforms provide intuitive interfaces, rapid access to information, automated data processing, and capabilities for visualization and modelling, all of which assist students during project development. In the context of engineering education, this enables more efficient prototyping, the evaluation of alternative solutions, and the optimization of design concepts. Consequently, technology evolves from a mere auxiliary tool into an active element of the engineering design and decision-making process.

In addition, the results indicate that students do not use AI tools solely to execute isolated tasks; rather, they gradually build skills to combine different platforms and functionalities into a unified workflow. This is particularly important in an engineering context, where solving complex problems requires integrating multiple technological resources, analytical approaches, and information sources. Observations of the teamwork revealed that students confidently applied AI to ideation, information structuring, programming, simulations, and visual representation of solutions, reflecting the development of practical digital competencies.

Despite these positive outcomes, the analysis reveals certain risks associated with an over-reliance on AI systems. A tendency was observed among some students to accept AI-generated solutions without sufficient critical analysis or engineering justification. This highlights the need for a balanced deployment of AI technologies, where automation supports rather than replaces analytical and critical thinking. Therefore, high technological functionality must be accompanied by the development of skills to evaluate the reliability, applicability, and limitations of AI-generated content.

The gathered data confirm that an AI-based educational environment ensures a high degree of technological efficiency and successfully supports engineering instruction. Simultaneously, the findings emphasize the necessity for pedagogical approaches that encourage not only the technical exploitation of AI but also an informed, critical, and responsible interaction with intelligent systems.

6.1.4 Analysis of Results in the "Design Thinking and Creativity" Domain

In the "Design Thinking and Creativity" domain, the distribution of results is more balanced than in the other evaluated domains. The largest share of students achieved a "very good" level (42%), followed by 33% at a "high" level. Concurrently, a more noticeable presence of the "good" (14%) and "fair" (8%) levels is recorded. These data indicate that while instruction through AI and Design Thinking successfully stimulates creativity and project-based thinking, this specific domain remains the most complex and difficult to master deeply.

These findings can be attributed to the nature of the Design Thinking process itself. Unlike technological functionality—where students interact with concrete AI tools and relatively clear operations—creative thinking requires a higher level of abstraction, flexibility, and the ability to generate original ideas. A subset of students demonstrated confidence in using AI platforms but had difficulty translating the generated information into innovative, non-traditional engineering solutions. This indicates that technological competence does not always automatically translate into high creativity.

At the same time, the results confirm that the AI environment possesses significant potential to support the creative process. The use of generative AI tools facilitates ideation, concept visualization, rapid prototyping, and the evaluation of alternative solutions. This establishes conditions that allow students to experiment more boldly and progress more rapidly through the distinct stages of Design Thinking. Nevertheless, creativity continues to depend heavily on the learners' ability to formulate problems, exhibit empathy toward end-users, and critically interpret AI-generated suggestions rather than merely applying them mechanically.

The lower proportion of students achieving a "high" level can also be linked to the fact that engineering education traditionally emphasizes analytical precision, accuracy, and algorithmic thinking. Conversely, Design Thinking requires a

tolerance for ambiguity, experimentation, and creative risk-taking. For a portion of the students, transitioning to this type of cognitive model likely demands more time, practical experience, and pedagogical support.

Furthermore, the results indicate that the AI-based environment is particularly effective at stimulating the initial stages of the creative process. However, developing deeper innovative capabilities requires supplementary pedagogical strategies, such as working with real-world case studies, interdisciplinary projects, team collaboration, and encouraging critical reflection on the ideas generated. This implies a need for a stronger emphasis on methodical guidance when applying Design Thinking, ensuring that AI tools are utilized not merely as a means of automation, but as a catalyst for creative and conceptual engineering thought.

6.1.5 Analysis of Results in the "Educational Experience and Student Impact" Domain

This domain recorded the highest proportion of students at the "high" level (67%), representing the strongest result among all measured metrics. Additionally, 23% achieved a "very good" level, while poor and fair values were minimal. This clearly demonstrates high motivation and engagement, as well as a positive emotional impact of the instructional model on students.

The observed outcomes can be explained by the characteristics of the contemporary student body, which is highly oriented toward digital technologies, interactive platforms, and rapid access to information. Students perceive AI tools as an intuitive part of daily communication, education, and professional development, which facilitates their adaptation to this type of educational environment. Working with AI platforms fosters a sense of autonomy, flexibility, and personalized support by enabling rapid ideation, information synthesis, solution visualization, and immediate feedback.

Additionally, the project-based nature of Design Thinking instruction encourages active participation, teamwork, and the practical application of knowledge within authentic engineering contexts. The combination of AI technologies and practically oriented tasks aligns the instructional process closely with the professional environments that students expect to enter. This yields a higher degree of satisfaction, a sense of relevance regarding the learning activities, and

stronger intrinsic motivation to participate in the educational process.

6.2 Statistical Analysis of the Results

The statistical processing of the data corroborates the trends identified in the qualitative analysis and allows for a more precise evaluation of the effectiveness of AI-based instruction through Design Thinking in engineering disciplines.

The calculated mean effectiveness indices reflect high values across all investigated domains, with the overall integral index reaching 4.24 out of a maximum possible 5.00 points. This value demonstrates a high overall level of effectiveness for the implemented educational environment and confirms that integrating AI technologies with the Design Thinking methodology creates favourable conditions for developing engineering competencies.

The highest mean index was recorded in the "Educational Experience and Student Impact" domain (4.50). This indicates that students perceive the learning process as motivating, interactive, and practically relevant. The high values in this domain can be explained by the alignment of AI tools with the digital culture of contemporary students. Interacting with intelligent platforms, generative AI systems, and interactive environments corresponds to how learners routinely search for, process, and utilize information. This enhances their sense of autonomy, engagement, and the personal relevance of the instructional process.

The second-highest value is in the "Technological Functionality" domain (4.34), indicating successful student adaptation to the AI tools used and effective integration of technology into the curriculum. The high effectiveness coefficient (88%) and low share of difficulties (6%) indicate that students not only use AI platforms confidently but also apply them effectively in the design, analysis, and development of engineering solutions. This is particularly important in the context of modern engineering training, where digital and AI literacy are becoming key professional competencies.

In the "Educational Effectiveness" domain, the mean index reaches 4.16, and the high-effectiveness coefficient is 81%. The data show stable acquisition of knowledge and competencies, as well as successful application of what has been learned in a practical project environment. The results confirm that AI integration supports not only access to information but also the development of analytical,

systems, and applied engineering thinking. At the same time, the presence of a small percentage of students with moderate results indicates that the effective use of AI requires a certain level of self-regulation, critical evaluation of information, and knowledge-structuring skills.

The lowest score, though still high, was in the "Design Thinking and Creativity" domain (3.94). Compared to the other domains, the highest variability in results was observed here

($\sigma = 1.03$), indicating greater differences in individual student performance. These results can be interpreted as an indicator that creativity, the generation of innovative ideas, and conceptual engineering thinking develop more slowly and require more prolonged pedagogical support. Although AI tools facilitate the processes of searching, combining, and visualizing ideas, they do not automatically guarantee original thinking. This suggests a need for more targeted inclusion of creative tasks, discussion formats, and problem-based scenarios in engineering education.

Additional insights are provided by the variability indicators. The standard deviation values are below 1.1 for all domains, which indicates relatively low variability and good consistency of the ratings. The lowest standard deviation was recorded for "Educational Experience and Impact"

($\sigma = 0.88$), demonstrating a relatively uniform positive perception of the training model among most participants. On the other hand, the greater variability in "Design Thinking and Creativity" suggests that the development of creative and innovative competencies may be more strongly influenced by individual characteristics, prior experience, and the ability to operate under uncertainty.

The results of the χ^2 test of independence shows that no statistically significant association is established between the evaluation domain and the

effectiveness level, $\chi^2(12, N = 256) = 20.72$,

$p = 0.055$. This means that the high ratings are not concentrated in a single domain but represent a general characteristic of how the AI-based learning environment is perceived. The obtained Cramér's

coefficient ($V = 0.164$) indicates a small effect size, suggesting that the observed differences between individual domains are not pronounced and do not yield statistically significant differences in the distribution of ratings.

Overall, the statistical analysis confirms the high general effectiveness of AI-based learning through design thinking. The data indicate that the model not only supports technological adaptation and the acquisition of engineering knowledge but also fosters an active, motivated, and engaged learning environment. The results indicate significant potential to expand similar educational practices in engineering education, while also highlighting the need to further develop pedagogical strategies to stimulate creativity and innovative thinking.

7 Conclusion

The findings of this empirical study confirm the substantial potential of AI-based instruction implemented within a Design Thinking framework in the context of engineering education. The integration of AI tools into the curriculum creates the conditions for more active student engagement, supports the acquisition of engineering knowledge, and fosters analytical, critical, and creative thinking. Simultaneously, the Design Thinking methodology provides a practically oriented framework for solving real-world problems through teamwork, ideation, prototyping, and solution testing.

The analysis of the results demonstrates a clear dominance of high effectiveness levels across all investigated domains. The most pronounced results were recorded in the "Technological Functionality" and "Educational Experience and Student Impact" domains, reflecting a smooth student adaptation to AI platforms, alongside high motivation and a positive attitude toward digitally assisted learning. The "Educational Effectiveness" and "Design Thinking and Creativity" domains similarly exhibited consistently high-performance metrics, which testifies to the successful development of engineering competencies and innovative problem-solving capabilities.

Despite these positive outcomes, the study indicates that the creative and conceptual dimensions of instruction remain highly sensitive to the need for supplementary methodical guidance. This highlights the importance of developing

pedagogical strategies that encourage deeper critical reflection regarding AI-generated solutions and more actively foster original engineering thought.

Overall, the research confirms that combining AI technologies with the Design Thinking methodology is an effective and promising model for modernizing engineering education. This approach establishes a foundation for preparing adaptable, technologically proficient, and creative specialists capable of meeting the challenges of the contemporary digital environment.

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Conflict of Interest

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