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Developing the student outcomes for the mechanical engineering course curriculum redesign: a survey with industry for mapping the competencies wanted for the next generation of engineers

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A mechanical engineering course is redesigning the curriculum not only to update it due to the appearance of emerging technologies and tools for engineering design, analysis, and manufacturing, but also to graduate engineers able to address the grand challenges that humanity, industry, and companies around the globe require. To fulfill this purpose, the first step in the redesign process is to define the new student outcomes and the competencies, abilities, and knowledge that graduating engineers must possess. Beyond the experience of faculty members, it is imperative to understand what companies expect from future engineers they will hire. To map expectations, a survey was conducted with 38 industries some with international operations – targeting directors, managers, and other leadership staff. This study aims to present the survey methodology, the key findings, and how these insights informed the development of the new student outcomes. In the questionnaire sent to these employers, they answered questions in three categories: technical skills, soft skills, values, and attitudes, with each question in three different levels. Each level corresponds to the stage of a future engineer within the company: an intern, an engineer to solve short-term problems, and an engineer to solve long-term problems. The goal of asking these questions at three levels is to assess whether the companies that will employ the future graduates of the course are already thinking about long-term problems and what kinds of professionals they must hire to address them, or if they are only focused on solving short-term problems. The survey revealed that industries value both technical and interpersonal competencies and skills among mechanical engineers. The most relevant core technical areas mapped include automation and control systems, thermal and fluid systems, manufacturing processes, CAD/CAM/CAE tools, and project management. Emerging skills such as data analysis, artificial intelligence, life cycle assessment (LCA), and product development using Product Lifecycle Management (PLM) and agile frameworks were also emphasized. Communication, teamwork, creativity, and the ability to connect theory with practice were noted as essential attributes. Additionally, knowledge of electrification systems, materials, safety regulations, and sustainability (ESG) was cited as increasingly important. The findings indicate that next-generation mechanical engineers must combine solid technical foundations with business awareness, critical thinking, and proactive engagement in continuous learning to meet future industry demands.

1. Introduction

A strategic reform of undergraduate engineering education that combines academia and industry can improve student development and job readiness. More hands-on training and ongoing curriculum updates help decrease graduates' transition time into employment, supporting an adaptable educational system aligned with current industry needs [1]. Collaboration between higher education and industry is important for effective engineering training, providing benefits such as hands-on experience, improved learning outcomes, and increased student motivation, while also posing challenges, including curriculum redesign and transitioning to the labor market [2]. Success factors include clear communication, shared goals, commitment, continuity, confidence, and collaboration, often achieved through problem-solving and product development activities. Project-based learning serves as a practical approach to connecting engineering education with industry needs, thereby gradually improving student performance in areas such as design, ethics, and teamwork [3].

Based on the perspectives of students, faculty, alumni, and employers, Ferreira et al. [4] argue that engineering curricula should be redesigned to better balance technical skills and interpersonal abilities. Higher education institutions need to include competencies such as communication, problem-solving, emotional intelligence, teamwork, leadership, creativity, innovation, critical thinking, and management, as employers often report deficiencies in graduates' soft skills. Stakeholders also stress the importance of practice-oriented curricula that combine theory and practical application through laboratories, seminars, internships, technical visits, and industry collaborations. Faculty point out gaps in project management, communication, and computing skills, recommending student-centered curricula, extracurricular activities, and ongoing programming training. Employers particularly highlight deficiencies in leadership and teamwork, and suggest implementing annual mini-internships and stronger engagement with industry partnerships. The study concludes that strong partnerships between universities and employers, active faculty involvement, evidence-based curricular updates, and alignment with societal and labor market needs are essential for developing engineers with both technical and behavioral skills [4]. Contextualization is another important aspect of engineering education, as it prepares students for responsible and socially aware professional practice. According to Kleine et al. [5], organizations such as ABET and NAE emphasize contextual competence, highlighting the importance of understanding engineering within social, cultural, and environmental contexts. Although widely recognized, contextualization is implemented in different ways, categorized into six modes: context tools, professional skills, real-world problems, design, sociotechnical thinking, and social impact. Tools like virtual reality and modeling software help connect core concepts, reduce misconceptions, and increase engagement by activating prior knowledge. Communication skills, especially writing and presentations, are also relevant for employability and can be developed through problem- and project-based learning [5].

Khan and Mourad [6] analyzed challenges in integrating Industry 4.0 technologies into engineering curricula and proposed a technology–pedagogy mapping framework to support evidence-based curriculum development. Their findings show varying adoption levels: IoT, big data, and simulation are more widely implemented due to lower entry barriers, whereas AI/ML and digital twins are adopted more slowly due to higher costs and complexity. Interdisciplinary approaches—especially project- and simulation-based learning—are linked to higher student satisfaction, better learning outcomes, and stronger industry partnerships. Effective alignment with industry largely depends on the depth of collaboration through advisory boards, co-teaching models, and competency-based curricula [6]. Similarly, Muzulon et al. [7] examined the competencies required of engineers in the context of digital transformation and Industry 4.0 through a systematic literature review. The development of practical and digital competencies is considered fundamental, along with the creation of a sustainable career ecosystem that extends beyond operational efficiency [8].

Chukwunweike and Salaudeen [9] studied how advanced computational methods enhance mechanical systems in modern engineering management. Tools such as Finite Element Analysis (FEA), Computational Fluid Dynamics (CFD), and artificial intelligence enable detailed simulations that support digital twins and predictive maintenance, improving efficiency and reducing operational costs. These techniques shift engineering from empirical modeling to data-driven simulation and algorithmic optimization, allowing for evidence-based decisions, better integration with CAD and product lifecycle management (PLM) systems, and a transition from reactive to predictive management. Despite benefits such as increased agility, innovation, and sustainability, challenges, including computational complexity, data governance, costs, and skill gaps, persist, underscoring their strategic importance in engineering practice and education [9]. Aminossadati et al. [10] proposed a pedagogical model to incorporate systems thinking and systems engineering into undergraduate mechanical engineering education. Structured around four progressive courses and guided by the V-Model and PLM, it aims to develop skills such as stakeholder analysis, risk management, sustainability, and lifecycle thinking. Grounded in engagement, personalization, autonomy, active learning, and critical thinking, the approach aligns academic training with industry practices through team-based projects, digital tools, reliability assessments, and data-driven decision-making, preparing engineers to tackle complex real-world problems [10].

An Autodesk and ASME report [11] also emphasizes the impact of Industry 4.0 on manufacturing, stressing the importance of engineers developing interdisciplinary skills such as artificial intelligence, data analytics, and sustainable design. Increased automation and cloud-based platforms demand stronger collaboration among professionals, leading to recommendations for modernizing engineering education through certifications and hands-on learning to foster a connected, agile manufacturing environment [11].

Several studies also point out specific curricular innovations. For example, developing additive manufacturing curricula aligned with emerging engineering education models encourages interdisciplinary collaboration, hands-on innovation, and active learning strategies like project-based learning and the flipped classroom, leading to improved student performance and better alignment with industry needs [12]. Other studies propose restructuring mechanical engineering education to address smart manufacturing by integrating AI, cyber-physical systems, and big data into traditional curricula [13]. These approaches often involve multimodal learning environments that use digital twins and cloud computing to solve real-world problems, along with data-driven monitoring of students' technical and ethical skill development. Strong collaboration between universities and industry, such as in CNC programming education, is also highlighted as important for preparing engineering leaders who can master advanced algorithms and foster interdisciplinary innovation [14,15].

Finally, sustainability is seen as a core principle in engineering education rather than just an optional topic. Main barriers include longstanding traditional views, limited cross-disciplinary integration, and not enough exposure to real-world challenges. Improving university–industry partnerships, using digital technologies to model sustainable solutions, and updating accreditation standards are recommended to help engineers develop ethical, social, and environmental skills aligned with the Sustainable Development Goals (SDGs), enabling them to tackle global issues such as climate change and resource depletion [16,17].

Given the context, this study aimed to design, implement, and analyze a survey to align industry expectations with the comprehensive development of a mechanical engineering undergraduate program, thereby mapping a competency-based curriculum reform grounded in the required knowledge, skills, and abilities.

2. Methodology

2.1 Research Design

This study adopts a descriptive and exploratory research design with a quantitative–qualitative approach, aiming to identify and analyze industry expectations regarding the competencies, skills, values, and knowledge required from future mechanical engineers. The methodology was structured to support the ongoing curriculum redesign of a mechanical engineering undergraduate program, ensuring alignment between academic training and current and future industrial demands.

The research is based on a structured survey applied to industry professionals in leadership positions, allowing the collection of standardized data from organizations that actively employ mechanical engineers. Given the applied nature of the study and its focus on curriculum decision-making, a purposive sampling strategy was adopted to obtain analytical representativeness across relevant industrial sectors rather than statistical generalization.

The questionnaire was developed by faculty members involved in accreditation processes and curriculum redesign, grounded in the existing student outcomes of the program, recognized engineering education frameworks, and internal strategic discussions on emerging technologies and professional competencies. Before its distribution, the instrument was internally reviewed to ensure conceptual alignment, clarity of wording, and coherence with the intended competency framework. A pilot application was conducted with a small group of industry partners to verify comprehensibility, adequacy of terminology, and estimated response time, leading to minor refinements in item formulation.

The final instrument included structured questions organized into technical competencies, complementary competencies, and values and attitudes. Responses were collected using a Likert-type scale to allow quantitative comparison across three professional development stages (intern, short-term problem-solving engineer, and long-term strategic engineer).

Data analysis was conducted using descriptive statistical methods, including frequency distribution and comparative analysis across the three professional levels. The open-ended responses were examined through thematic grouping to identify recurring suggestions and emerging competencies not initially listed in the questionnaire. Convergence of responses across different sectors and company profiles was interpreted as an indicator of thematic consistency, reinforcing the analytical robustness of the findings within the exploratory scope of the study.

2.2 Target Population and Sample

The number of participating companies (n = 38) was defined based on the exploratory nature of the study and the objective of obtaining a diversified and sector-representative perspective of the industrial environment that absorbs mechanical engineering graduates. Rather than pursuing statistical representativeness in a probabilistic sense, the study adopted a purposive sampling strategy, aiming at analytical representativeness and diversity of industrial contexts.

The companies were intentionally selected according to the following criteria:

Employability relevance – Priority was given to organizations that historically employ a significant number of graduates and interns from the mechanical engineering program, ensuring that the survey captured expectations from companies directly connected to the professional trajectory of the students.

Company size and organizational complexity – Medium- and large-sized companies were prioritized, as they typically present structured engineering departments, defined competency frameworks, and strategic planning processes, which allow clearer identification of short-, medium-, and long-term professional expectations.

Sectoral diversity – The sample includes companies operating in different industrial sectors, such as automotive, aerospace, general manufacturing, industrial equipment, and other engineering-intensive segments. This diversity was sought to avoid sector-specific bias and to capture transversal competencies required across multiple industrial domains.

Market relevance and leadership position – Several participating companies are recognized as leaders in their respective sectors, including firms with international operations. Their inclusion contributes to aligning the curriculum redesign not only with local demands but also with global industrial trends.

The final number of 38 companies was considered sufficient to achieve response convergence and pattern stability in the analysis, particularly given the structured nature of the questionnaire and the consistency observed across different sectors and professional levels. The recurrence of similar competency priorities among companies from distinct industrial domains indicates that the sample size was adequate to support curriculum decision-making within the scope of this study.

2.3 Survey Instrument Design

A structured questionnaire was developed by the faculty members involved in the curriculum redesign process, based on:

- The existing student outcomes of the mechanical engineering program;
- Accreditation requirements and reference frameworks in engineering education;
- Internal discussions on emerging technologies and professional competencies.

The questionnaire was organized into three main categories:

- Technical skills and knowledge
- Soft skills and interpersonal competencies
- Values, attitudes, and professional behavior

Each category contained multiple items (not important at all; of little importance; neutral; important; extremely important) addressing both traditional engineering competencies and emerging demands related to digitalization, sustainability, and innovation. A distinctive feature of the survey methodology is the evaluation of competencies across three professional stages, reflecting the expected evolution of a mechanical engineer within a company (intern or entry-level trainee; engineer focused on short-term problem solving; engineer focused on long-term and strategic problem solving).

For each item in the questionnaire, respondents were asked to assess the relevance or importance of the competency at each of these three levels. This structure allowed the analysis of whether companies prioritize immediate operational needs or demonstrate concern with long-term strategic capabilities and leadership development.

The questions were:

- **Technical competencies**

T01.) Ability to perform quick estimates and order-of-magnitude calculations;

T02.) Proficiency in manufacturing and production processes;

T03.) Proficiency in the analysis, design, and installation of mechanical machines and equipment;

T04.) Proficiency in CAD/CAM/CAE computational tools;

T05.) Proficiency in automation and control of electromechanical systems;

T06.) Proficiency in the analysis, design, and installation of thermal and fluid systems;

T07.) Proficiency in maintenance management and operation of industrial plants and equipment;

T08.) Proficiency in product development (PLM – Product Lifecycle Management);

T09.) Project management;

T10.) Do you suggest other technical competencies not listed? Please describe.

- **Complementary competencies**

C.01) Proficiency in written and oral communication;

C.02) Proficiency in teamwork, effectively collaborating with colleagues and supervisors;

C.03) Proficiency in project management, including planning and execution;

C.04) Creative and efficient problem-solving skills;

C.05) Leadership capability in creative work environments;

C.06) Knowledge to lead the transformation of the company toward Industry 4.0 and artificial intelligence environments;

C.07) Knowledge of the major challenges facing humanity, to inform and guide the company's external policies;

C.08) Knowledge of ESG principles for the proposal and implementation of internal policies;

C.09) Do you suggest other complementary competencies not listed? Please describe.

- **Desired values and attitudes**

V.01) Ethical principles of the mechanical engineering profession;

V.02) Social responsibility and commitment to the community;

V.03) Innovation and continuous improvement in professional activities;

V.04) Rigor and accuracy in the execution of tasks;

V.05) Ability and willingness for continuous learning;

V.06) Do you suggest other values and attitudes? Please describe.

2.4 Data Collection Procedure

The questionnaire was distributed electronically using an online survey platform. Invitations were sent directly to selected professionals via institutional contacts maintained by IMT, ensuring that respondents had decision-making or leadership roles within their organizations.

Data collection occurred over a defined period, during which reminders were sent to increase the response rate. Participation was voluntary, and respondents were informed about the academic purpose of the study and the confidentiality of their responses.

2.6 Data Analysis

The collected data were analyzed comparative analysis across the three professional levels. This quantitative analysis was complemented by a qualitative interpretation of trends and patterns observed in the responses.

The results were mapped against the proposed student outcomes of the mechanical engineering program, enabling the identification of:

- Core competencies consistently valued across all professional stages;
- Skills that gain importance in medium- and long-term professional development;
- Emerging technical and transversal competencies that should be incorporated into the redesigned curriculum.

3. Results and Discussion

The results presented below are organized by question and, within each question, by professional engineering level.

3.1 Technical competencies

For the technical competencies, graphs were generated and are presented in Figures 1 through 5 below.

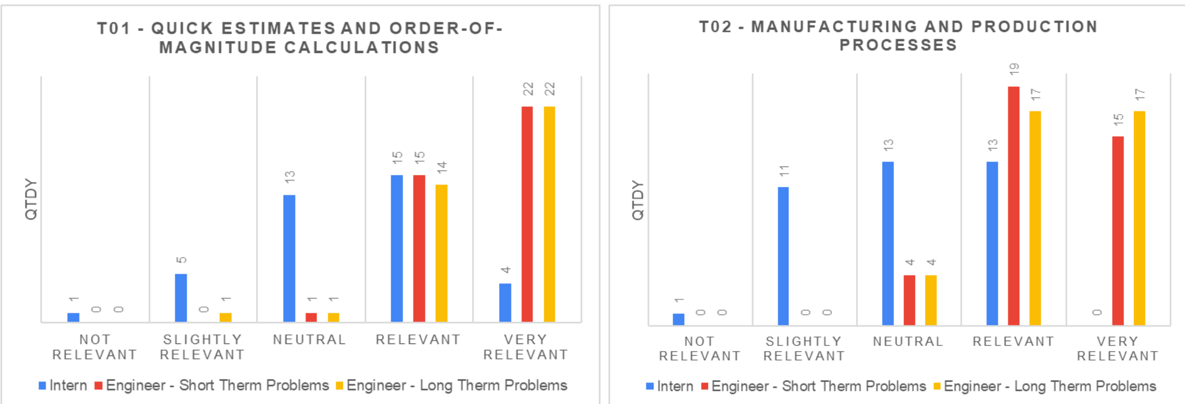

Figure 1 – Left: Results for question T01; Right: Results for question T02

The results presented in Figure 1 (left) are consistent with expectations, showing an increase in relevance as professionals progress throughout their careers. One noteworthy aspect is the importance of this competency already at the internship level, which reinforces the relevance of this knowledge in the early years of engineering education. The results presented in Figure 1 (right) indicate that companies expect interns to have already developed this topic during their academic training, since upon graduation its relevance for newly graduated engineers is very high.

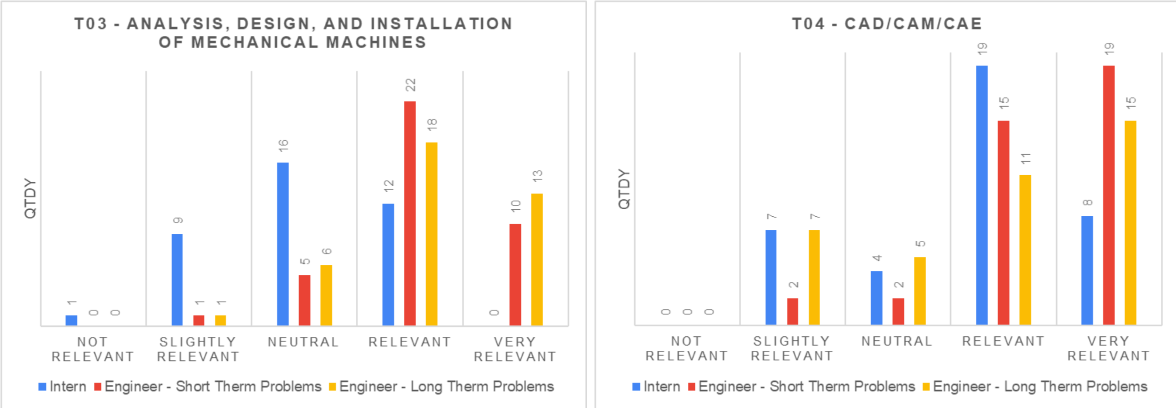

Figure 2 – Left: Results for question T03; Right: Results for question T04

In Figure 2 (left), the same pattern observed in Figure 1 (right) is identified, with the only change being the increase in relevance at the transition from intern to short-term engineer. For the CAD/CAE/CAM skill presented in Figure 2 (right), expectations for interns are very high, with companies expecting them to already have a solid background developed during their academic training in order to meet industry demands. A noteworthy point is that this skill remains highly relevant after the transition to short-term engineer.

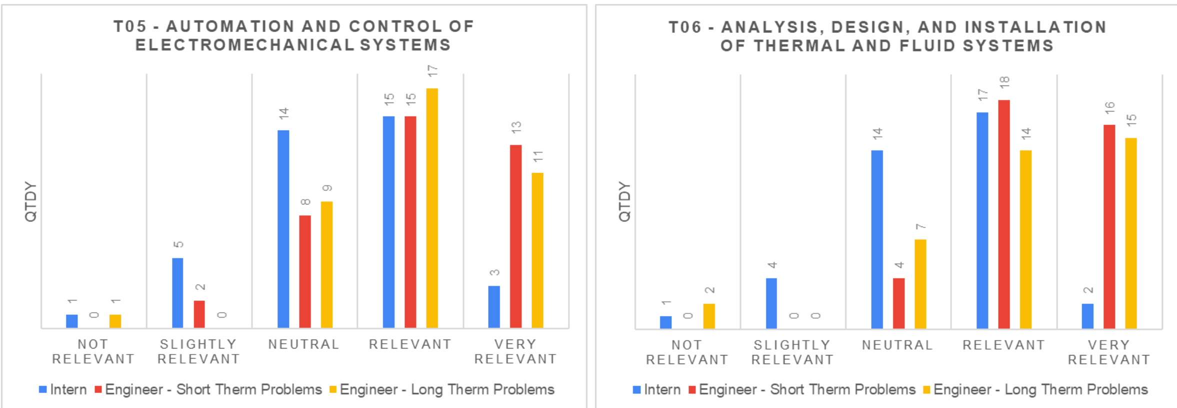

Figure 3 – Left: Results for question T05; Right: Results for question T06

For the skill presented in Figure 3 (left), a neutral-to-moderate expectation is observed for interns, with a slight increase in relevance for more experienced engineers. The same behavior was observed for question T06, as presented in Figure 3 (right).

Figure 4 – Left: Results for question T07; Right: Results for question T08

Both questions presented in Figure 4 exhibit the same relevance pattern across the different professional engineering levels. It is worth highlighting, in Figure 4 (right), the significant importance of PLM knowledge even at the internship level, which may represent a differentiating factor when seeking a first job opportunity.

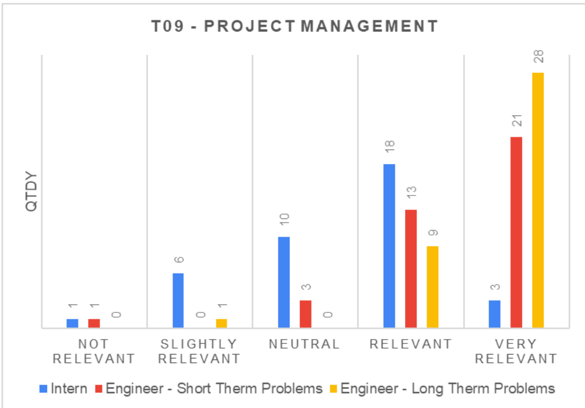

Figure 05 - Results for question T09

Question T09 in Figure 5, related to project management, presented an expected pattern, with greater relevance attributed to more experienced engineers. Nevertheless, the relevance level assigned to interns indicates that companies already expect them to be capable of managing small projects and coordinating limited tasks.

Regarding Question T10, which allowed respondents to mention topics not previously listed, data analysis, artificial intelligence, knowledge of technical standards, and task management software were the most frequently highlighted areas. Some of the items mentioned were addressed in the questions of Sections 3.2 and 3.3 and were therefore not considered in this count.

3.2 Complementary competencies

For the complementary competencies, graphs were generated and are presented in Figures 6 through 9 below.

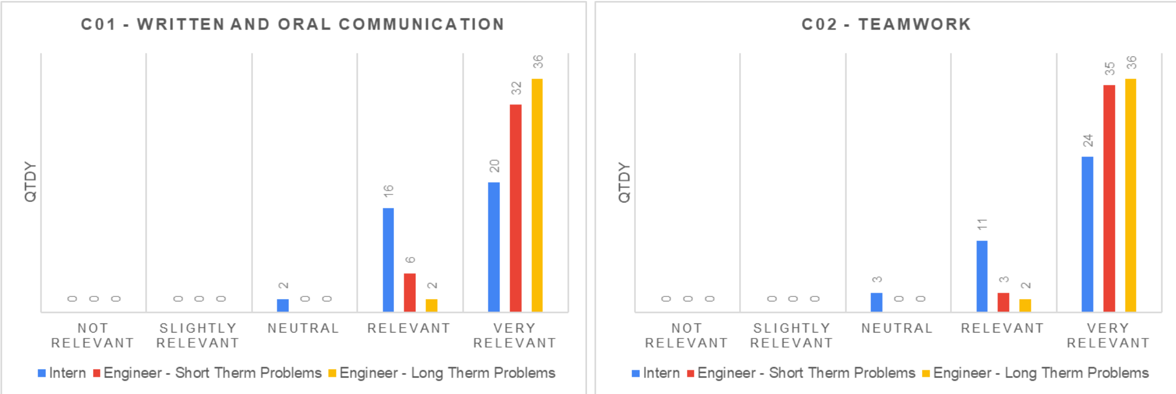

Figure 6 – Left: Results for question C01; Right: Results for question C02

Both questions presented in Figure 06 indicate that communication and teamwork skills are expected even at the earliest stages of professional development. Companies already expect universities to foster these competencies from an early stage, delivering engineers— even at the internship level— with strong development in these skills.

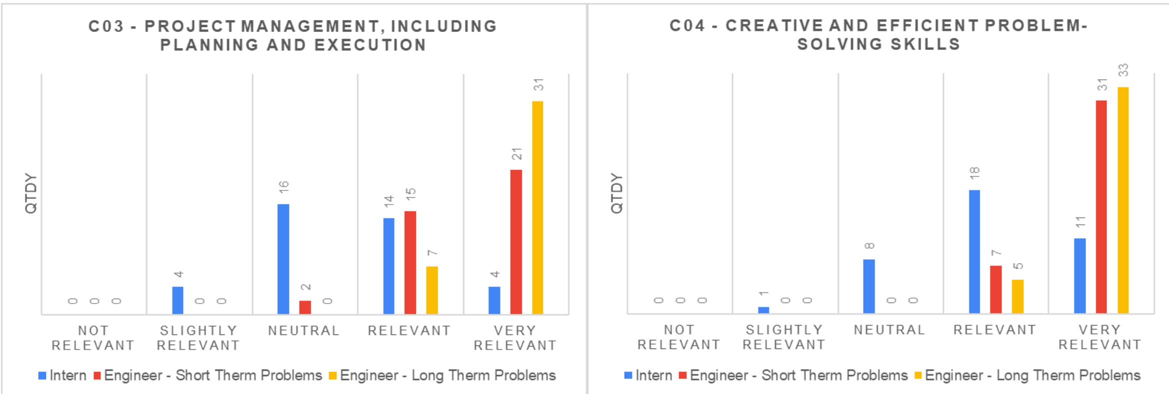

Figure 7 – Left: Results for question C03; Right: Results for question C04

In Figure 7 (left), an expected pattern was observed, with relevance increasing throughout professional development while maintaining a neutral-to-moderate level of importance for interns. In contrast, for the focus on creative solutions shown in Figure 7 (right), a higher level of relevance is already expected for interns, indicating that companies expect this skill to be present prior to professional experience, rather than being developed during the internship period up to graduation.

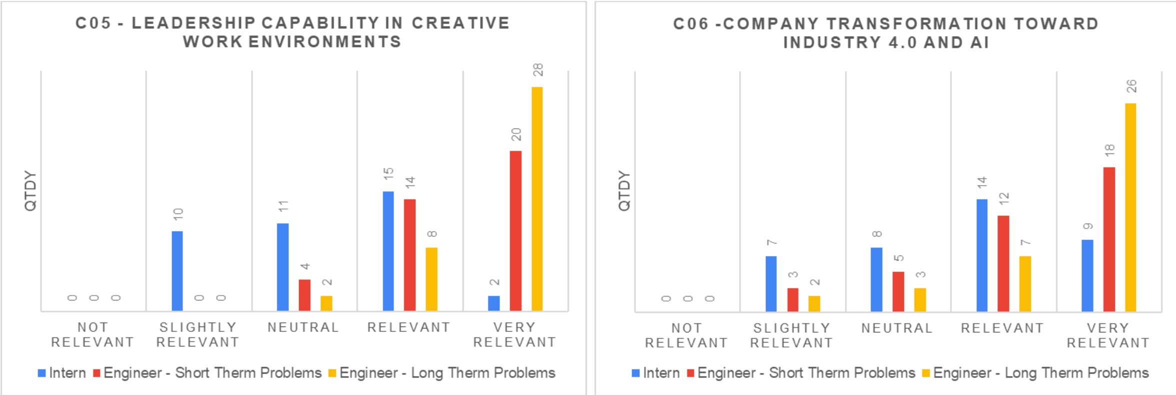

Figure 8 – Left: Results for question C05; Right: Results for question C06

Both results presented in Figure 8 show patterns similar to those observed in most of the questions. In the left figure, the results for interns are evenly distributed in terms of the relevance of leadership skills, making the analysis inconclusive. Regarding the right figure, a higher level of relevance was expected for intern and short-term engineer positions; a possible explanation is that the companies' areas of operation may not yet be fully integrated with these skills.

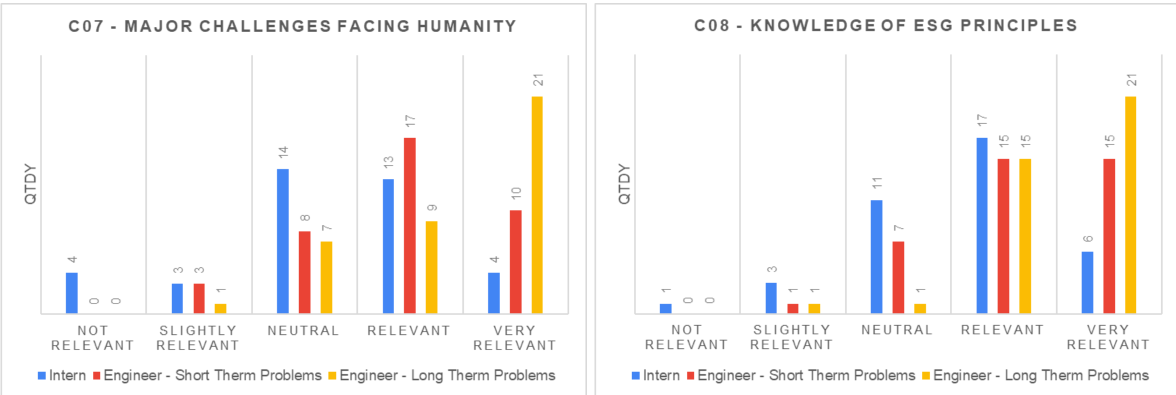

Figure 9 – Left: Results for question C07; Right: Results for question C08

For the results presented in Figure 9, both highlight an increasing relevance of topics related to global human challenges, with particular emphasis on ESG policies, which have been gaining prominence within companies. Concern and knowledge regarding these guidelines are already expected starting at the internship level, as they are anticipated to remain key topics in the coming years.

In Question C09, companies were allowed to freely report topics they consider relevant, with emphasis on knowledge of legislation, economics, finance, user experience, and diversity. Additionally, resilience and proactivity were also highlighted in several responses.

3.3 Desired values and attitudes

Regarding values and attitudes, the results are presented in Figures 10 to 12. Notably, the questions exhibited high levels of relevance across all professional levels, indicating that these are expected values to be developed from an early age.

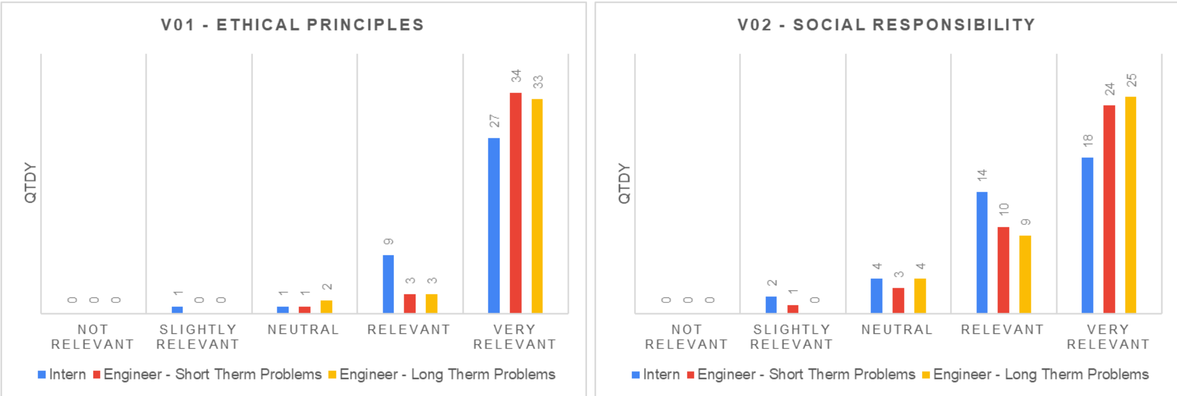

Figure 10 – Left: Results for question V01; Right: Results for question V02

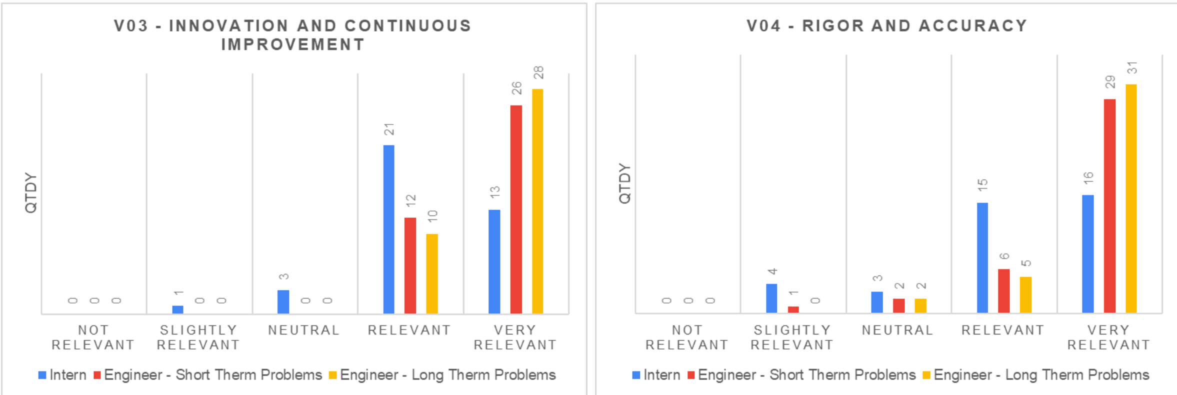

Figure 11 – Left: Results for question V03; Right: Results for question V04

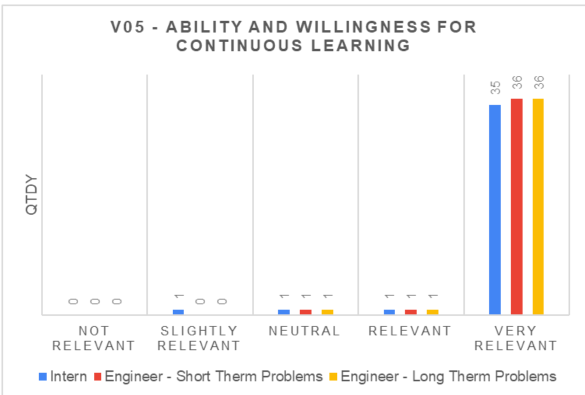

Figure 12 –Results for question V05

3.4 Application of the results in the new curriculum framework

The results from the industry survey played a central role in guiding the redesign of the mechanical engineering curriculum. The competency mapping identified through the questionnaire allowed faculty to reassess the balance between fundamental engineering knowledge, digital and analytical tools, and professional competencies required by industry.

Based on the survey findings, the curriculum reform was structured around three complementary axes: strengthening core engineering fundamentals, expanding digital and computational competencies, and fostering transversal professional skills. The strong emphasis placed by companies on CAD/CAE/CAM tools, manufacturing processes, and project management motivated the reinforcement of design-oriented courses and the integration of digital engineering tools across multiple subjects. Earlier exposure to engineering software environments was introduced to progressively develop students' design and simulation skills.

Another important outcome of the survey was the recognition that companies expect interns to already possess well-developed communication and teamwork abilities. In response, the program expanded project-based learning activities and reinforced extension initiatives connected with the external community. These initiatives require students to interact with stakeholders outside the university environment, strengthening communication, teamwork, and the organization of engineering projects with real society impact. Extensional activities also contribute to developing students' awareness of the social dimension of engineering practice.

Emerging competencies highlighted in the survey—particularly data analysis, artificial intelligence, and digital engineering tools—motivated a revision of the first four semesters of the program. A structured computational pathway was introduced, including basic programming, statistics, data analysis, and artificial intelligence, ensuring that students acquire the analytical background to apply modern data-driven methods in advanced engineering courses.

These changes were implemented together with introductory courses such as *Design for Engineering*, which emphasizes user experience in engineering solutions, and a business-oriented course introducing entrepreneurial thinking and innovation concepts. Ethical responsibility and social awareness are addressed from the first semester, reinforcing the role of engineering in responding to societal challenges.

4. Conclusions

The present study aimed to gather information from companies that employ engineers graduated from a mechanical engineering program in order to align employers expectations with what can be taught in undergraduate engineering programs.

Regarding technical competencies, it was observed that companies have high expectations for interns, already requiring a very solid theoretical background. In particular, the strong relevance of CAD/CAE/CAM knowledge was highlighted, as it constitutes a fundamental basis for new product development.

Concerning complementary competencies, oral and written communication as well as teamwork stood out in the results. Employers already expect these skills to be fully developed at the internship level, which can significantly facilitate the integration of professionals with their teammates and supervisors. Furthermore, knowledge related to major global challenges and ESG policies has been gaining relevance within companies, aligning organizational principles with societal demands.

With respect to human values, these were found to be non-negotiable. Companies indicated that even at the earliest stages of professional development, engineers are expected to demonstrate social responsibility, ethics, respect for colleagues, as well as a continuous pursuit of knowledge updating and innovation.

Beyond identifying the competencies expected by industry, the results of this study also contributed directly to the ongoing curriculum redesign of the mechanical engineering program. The mapping of technical, complementary, and behavioral competencies provided a structured basis for updating course contents and pedagogical strategies throughout the program. In particular, the identification of emerging competencies related to data analysis, artificial intelligence, and digital engineering tools motivated the creation of a computational pathway introduced during the first four semesters of the curriculum.

This pathway, combined with project-based learning activities, early exposure to engineering design, financial perspectives, and discussions on ethics and social responsibility, aims to prepare students to address contemporary engineering challenges while maintaining a strong foundation in core mechanical engineering principles.

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