Humanities in Engineering: Building Responsible Innovators for Tomorrow

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ABSTRACT

Engineering education faces the challenge of preparing professionals capable of dealing with complex global problems, requiring an educational approach that goes beyond traditional technical education. The inclusion of humanities in engineering education promotes the development of transformative skills such as empathy, critical thinking, and the ability to solve social and ethical problems in a way that broadens the perspective of future engineers. Initiatives such as the use of historical examples and interdisciplinary projects demonstrate that these approaches not only improve learning but also make engineering more attractive to diverse audiences, fostering a more inclusive and innovative professional vision. This article argues that the integration of these areas is fundamental for the development of core competencies that directly impact the quality of innovations in a world that is constantly changing. Also, the quality in engineering is significantly improved when engineers are educated to understand and apply humanities knowledge in their professional practices, ensuring a holistic and responsible approach, which leads us to conclude that integrated curricula that incorporate humanities prepare engineers for future challenges, promoting greater awareness of the consequences of their actions. In this article, we highlight some educational initiatives that already apply these concepts, observing improvements in student empathy, ethics, and flexibility, qualities that are indispensable for excellence in the practice of modern engineering. Therefore, engineering education, enriched by a foundation in humanities, prepares professionals not only to solve technical problems but also to lead the implementation of solutions that benefit all of society.

Keywords: Engineering education, Humanities integration, Ethical leadership, Transformative competencies, Social responsibility

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Introduction

Reflections on the social responsibility of engineers have been around for a long time, but they still encounter significant resistance in academic training, which tends to prioritize technical aspects to the detriment of broader approaches.

With the advancement of technology and its increasing integration into everyday life, it becomes necessary to consider the ethical and social impacts of technological innovations. In general, technology is seen as an agent that not only transforms global society but also has enormous potential to positively impact people's quality of life. At the same time that it is impossible to deny the benefits and protagonism of technological innovations, it is not difficult to argue and find examples of what social and environmental costs have been necessary for us to enjoy the full technological potential in the most diverse activities of daily life, from the most trivial to the most complex, which allows us to reflect on the condition or characteristic of technological innovations, to say the least, paradoxical.

Such a characteristic of technology is capable of arousing and feeding discussions of the most varied in the most diverse environments, but it seems that it still does not occupy the due space or arouse due attention in the schools of engineering and related areas that are responsible for training those who will be the main actors for producing innovations that translate into technological advances that coexist with us and transform and even shape the lives of people and all a society.

Another reflection that is appropriate when it comes to the performance of the engineer is his ability to solve a problem. Is it possible that a problem is solved when others arise as a consequence? It seems that in many cases, what we have is the resolution of problems, even if they are complex, but the solution, properly speaking, may be far away. What the world needs are engineers who are able to provide solutions to problems, many of which are generated as a consequence of major technological advances, imposing greater ethical and social demands on current engineers.

Only these two reflections, obviously, would be a strong argument for thinking about the training of engineers. Considerations and arguments about the social responsibility of engineers are long-standing. Despite this, there still seems to be resistance to bringing elements to the training of engineers that will allow and encourage them to reflect and have a broader and, consequently, more responsible look at their performance.

What is proposed from this brief explanation is the approximation of the humanities in the teaching of engineering and taking the discussion to the scope of quality engineering; the approximation between these areas can transcend the concern and need to design products and processes with quality under the most varied technical aspects. This approach will help engineers to think about their projects to meet the needs and expectations of users in different cultural contexts, including considering the emotional and social needs of users and conducting a quality assessment based not only on technical terms but also in terms of impacts on society in line with the principles of environmental, social, and corporate governance (ESG).

This approach may occur both with the insertion of humanities disciplines and different approaches in disciplines of an engineering course or in the execution of projects, which seem to be the most appropriate to develop a mentality focused on social and

environmental responsibility in engineers. Thus, this article is organized as follows: in the section "Humanities and Engineering: A Path to Ethical Leadership," some references have been presented that address the insertion of humanities in engineering education; in the section "Integrating Humanities in Engineering Education" are presented some experiences e suggestions about the insertion of humanities in engineering education as well some results; and, in the section "Conclusion," the conclusions.

Humanities and Engineering: A Path to Ethical Leadership

Before addressing the reasons for introducing the humanities into engineering, it is important to contextualize how engineering education was structured during the twentieth century. The development of engineering as we know it today has its roots in the education of engineers in academic institutions that, during the twentieth century, responded to the needs of a labor market governed by the Taylorist-Fordist model, which demanded engineers with a technical and specialized background, without the need for a very deep and broad understanding of the implications and consequences of their actions. With the emergence of Toyotism in the same century, it began to demand for multipurpose and quality-focused professionals adjusted to consumer demands. This scenario, combined with the effects of globalization, has profoundly transformed the labor market, leading to job shortages and uncertainties, forcing educational institutions to rethink how to prepare engineers for a competitive environment that demands skills beyond technical ones.[1]

The challenges facing engineers today have broadened significantly compared to the past, including issues such as climate change, sustainability, and a broader ethical responsibility, requiring new skills and reformulations in engineering education.[2,3] Specifically, Martin, Diem, Karwat, et al. identified through interviews and qualitative studies that current engineers need to better understand the ethical and justice dimensions related to the environmental and social impacts of their projects.[2] Similarly, Chance, Lawlor, Direito, and Mitcell, through interviews, investigated how civil engineers perceive and enact ethical considerations, contrasting this with their understanding of health and safety, corruption, and bribery in their work, pointed out that the ethical responsibility of civil engineers needs to go beyond traditional regulations, considering global goals and broader social impact.[3]

Bringing the considerations to the current and future context, with the most diverse challenges not only technical but also ethical, social, and environmental, a broad-based general education is crucial for the development of critical thinking in engineering students and future engineers.[4] The way in which the engineer's own career develops presents elements that justify a reflection on how engineering education was structured throughout the twentieth century and that still cultivates its roots today. As engineers progress in their careers, they face increasing challenges related to managing people and projects, increasing the importance of their decisions. This intensifies their interactions with employees, consumers, and competitors, highlighting the relevance of the humanities for effective leadership. Skills such as communication, legal knowledge, business ethics, psychology, and conflict management become crucial.[5] These skills are fundamental not only for the operation and documentation of projects but also for business adaptation and innovation, transcending mere technical execution.[6]

In view of this, in recent years, there have been discussions and initiatives that have led engineering education institutions to rethink their courses and methodologies to enable the development of soft skills that would meet, if not totally, at least a good part of the needs pointed out in Brazilian curricula guidelines for engineering courses.[7] However, modern scientific technology poses value-laden questions that engineering, in its traditional execution form, may not be able to provide. These questions actually require *insights* from the humanities, which can provide an ethical, cultural, and social context necessary for responsible engineering practice.[8] Integrating philosophy in engineering education, with its emphasis on critical thinking and ethical considerations, supports engineers in questioning assumptions, considering different perspectives and approaches, and tackling complex ethical dilemmas.[9] Critical thinking, in turn, complements logical thinking, which is already abundant in engineering education. The goal is to help students develop higher-order thinking skills, moving beyond rote memorization and basic comprehension to analysis, synthesis, and evaluation.

Considering the implications of modern scientific technology and the innovations already present today and those that are to come, it is necessary to think about an engineering education that goes far beyond the already known soft skills. It is necessary to think about an engineering education that develops transformative competencies.[10] In the work developed by Malykhin, Aristova, and Opalink, the theme is addressed by arguing about the didactic potential of the humanities in the development of transformative skills among computer engineering and information technology students, which are: 1) *value creation*, which includes the development of a sense of purpose, curiosity, open-mindedness, critical thinking, creativity, collaboration, adaptability, and agility; 2) *reconciliation of conflicts and dilemmas*, which involves cognitive flexibility, perspective-taking skills, empathy, respect for others, problem-solving skills, conflict resolution skills, resilience and tolerance for complexity and ambiguity; and 3) *taking responsibility*, encompassing the locus of control, sense of integrity, compassion, respect for others, critical thinking, self-awareness, self-regulation, and reflective thinking.[11]

Despite the arguments in favor of bringing the humanities and engineering areas closer together, the current engineering curricula do not seem to go much beyond the development of soft skills. In Cech's article, a survey is presented, and the results indicate a decrease in the engagement of engineering students in

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social causes as they advance in graduation. This phenomenon is most pronounced in traditional curricula, where non-technical considerations are often seen as irrelevant.[12] This trend of disengagement, which seems to be rooted in the educational culture of engineering in which any non-technical considerations are considered irrelevant to engineering work, is also reinforced by the study by Josa and Aguado, which also notes the neglect of social and humanistic issues in engineering education.[13]

Evaluating, then, the global scenario, with its needs and complexities, it is possible to conclude that there is a pressing need to work on the curricula of engineering courses so that they contemplate the development of competencies that can be facilitated with the insertion of humanities in engineering education.[9,14]

Integrating Humanities in Engineering Education

There are different possibilities and proposals to include humanities in engineering education, from the insertion of specific disciplines to project-based approaches and challenges in which students are led to apply engineering to find solutions that put them in contact with social, environmental, and humanistic issues.[9] Empirical results demonstrated, from pre- and post-intervention questionnaires and qualitative interviews with students, that the insertion of literature in technical disciplines resulted in significant advances in interpersonal skills, such as effective communication, empathy, and collaborative work. This study proves, in practice, the concrete benefits of the curricular integration of the humanities, contributing to the integral and ethical development of future engineers.[15]

An understanding of history is fundamental to engineering, as it enables knowledge that leads to important decision-making when it comes to the design or development of new technologies, allowing students to evaluate technical solutions based on historical experiences, as evidenced by Klochkova, Bolsunovskaya, and Shirokova.[5] In addition, understanding how models and theories evolve improves processes and the effectiveness of solutions. Practical examples such as the Introduction to Development Aid program of the Polytechnic University of Valencia show that empathy and social awareness, cultivated through real projects, lead to a greater concern for environmental justice and sustainability, positively impacting the training of engineers.[16]

Continuing in the historical perspective, the discipline of History and Philosophy in Electrical and Computer Engineering, offered to graduate students and open to undergraduate students from State University of Campinas, provides an immersion in philosophy and theory in electrical and computer engineering through the development of texts, reviews, and discussion of videos on subjects in the area and main names in electrical engineering and computer engineering. Through a three-minute video produced by students about their research topics or interests related to the areas of the discipline, students develop the power of synthesis and argumentation.[17] In this context, history studies allow engineers to learn from past failures as examples of ill-founded technical decisions and make more technically robust ones with a broader, long-term view.[14]

Others continue in this vein, advocating a broad interdisciplinary approach, including literature, philosophy, history of science, and the arts, providing a deeper understanding of the social and cultural contexts of the technical solutions proposed by engineers.[18,19] In an empirical study conducted by Davis, Joshi, Czerwionka, et al., engineering students participated in a course that used international case studies addressing literature, history, philosophy, and arts applied to real technical problems. Pre- and post-course assessments, using structured questionnaires and qualitative analysis of written responses, showed an increase in students' ability to utilize systems thinking, consider broader cultural and social contexts in their analyses, and define goals.[18] Lucietto and Peters, in a conceptual review of recent literature, also highlighted the importance of disciplines such as history and literature to foster critical thinking and ethical awareness in future engineers, helping them to better perceive the human and social impacts of the technologies developed, increasing, also, student engagement, and promoting inclusivity.[19]

From Yu, Li, and Wang comes the proposal to create an Engineering and Humanities discipline aiming at humanistic instrumentalization in engineering students, in addition to highlighting the need for a necessary dialogue between the humanities in engineering.[4]

The teaching of humanities in engineering should be approached through problem-solving, a technique familiar and well-accepted by engineering students, highlighting that this can lead to the development of superior and more efficient projects, arguing that leadership skills, such as conflict management and adaptation to diversity, are essential in this process.[20] Another possibility is combining challenge-based learning and activity-based learning, as suggested by Malykhin, Aristova, and Opalink, to prepare computer engineering and information technology students to face contemporary challenges.[11]

Extension activities can also enrich the teaching of the humanities, as demonstrated in the project of the Polytechnic University of Valencia, where students from different areas developed greater social awareness and responsibility through collaborative work on real challenges, resulting in a significant increase in students' argumentation capacity and sense of responsibility. Interdisciplinary programs, such as the one at the Polytechnic University of Valencia, show how real projects can connect technical and social skills, promoting culturally appropriate and sustainable solutions.[16] In Adair and Jaeger, this is reinforced by the mention that open-ended problem-solving assignments and reflective writing are effective methods for embedding critical thinking into engineering education. These approaches encourage students to grapple with ambiguity, consider multiple perspectives, and justify their decisions. The authors bring an initial

course experience that introduces students to critical thinking concepts and provide a foundation, but continuous integration into all engineering modules ensures these skills are reinforced and applied in diverse contexts.[6]

Addressing complex global issues such as water scarcity, hunger, and the conservation of natural resources requires an interdisciplinary educational approach in engineering, or the study of philosophy encourages students to question their actions and develop skills useful in a variety of professional situations, from project presentations to conflict management. Big challenges are complex problems that cannot be solved with just one area of knowledge. Addressing these problems in an interdisciplinary way is an opportunity to bring the humanities into engineering education.[13]

Barreto and Pasini suggest the use of artistic paintings and photographs in traditional engineering disciplines as a backdrop for concept development. Mentioning one of the examples covered in the article is Katsushika Hokusai's "The Great Wave the Kanagawa," a woodcut from 1931. Some ideas include using woodblock printing to study stability in ships and using the work to demonstrate principles of stability, such as the effect of ship pitch on waves and the relevance of center of gravity and buoyancy. In the hull design study, one can discuss the design features of ship hulls, addressing the shape of the hull and its resistance to waves. Regarding structural strength, the image can be used to exemplify how waves and the water force impact the structure of ships and the need to consider these forces in naval design. Another example is the use of the painting "Pittsburgh Factory Scene" by Joseph Stella, which depicts the context of industrialization and the transformation of American society and economy in the early twentieth century. For Civil Engineering and Occupational Safety, Lewis Hine's photographs depicting the construction of the Empire State Building can be used. In this paper, the authors seek to demonstrate that good engineering is as much a matter of intuition and nonverbal thinking as it is of equations and computation.[21] As related to the National Academies of Sciences, Engineering, and Medicine, initiatives such as Howard University's capstone course demonstrate that multidisciplinary teams composed of engineering, marketing, and art students can generate innovative solutions and integrate different perspectives.[22]

There are not many studies that present quantitative or qualitative results on the inclusion of the humanities in engineering education, but rather some empirical results that can be influenced by methodologies found in institutions, teaching experience, or institutional resources.[7] In the National Academies of Sciences, Engineering, and Medicine, several works describe or report the experiences of different American educational institutions, even with methodological limitations. Some results are presented in Table 1.[22]

According to the National Academies of Sciences, Engineering, and Medicine, studies of various American educational institutions revealed that the inclusion of humanities and arts in the curriculum generally leads to several positive outcomes. These include enhanced student engagement and improved educational practices across the board.[17]

- Increased motivation and engagement in self-regulated learning.
- More frequent use of critical thinking skills.
- Higher self-efficacy.
- Higher value placed on learning tasks.

Table 1 | Results or evidence

Institution	Strategy or Practice	Results or Evidence
Howard University–mechanical engineering students	Option of enrolling in a multidisciplinary capstone course with students from the departments of electrical engineering, marketing (in the business school), and art (in the Division of Fine Arts).	Without empirical evidence, faculty noted that students enhance their understanding of engineering's practical aspects in real-world settings, develop abilities to work effectively in multidisciplinary teams, navigate the transition from classroom to industry, improve communication skills, and increase their job prospects.
Dwight Look College of Engineering at Texas A&M University	The first-year curriculum integrates areas such as ethics, writing, graphics, problem-solving, physics, calculus, and chemistry.	Students enrolled in the first-year integrated program outperformed their peers in traditional curricula, showcasing enhanced critical thinking skills and superior performance in calculus and physics. They also achieved higher overall grade point averages, developed advanced computer skills, and demonstrated a greater ability to work effectively in team settings.
Colorado School of Mines	Students in the first-year curriculum engage in integrated project modules and active-learning strategies. They participate in a two-semester interdisciplinary seminar to explore the connections among topics from science, humanities, and engineering courses, and they are involved in peer study groups to enhance collaborative learning and understanding.	Engineering students who participated in the integrated program showed a graduation rate of approximately 25% higher than those in the traditional curriculum. A follow-up survey conducted 5 years later revealed that these students felt the program had enriched their academic preparation, notably enhancing their ability to connect course topics, bolstering their critical thinking, raising their ethical awareness, and strengthening their communication skills.
Olin College	The faculty of engineering offers two options to students taking an introductory materials science course: an integrated materials science-history course co-taught by faculty in engineering and history or a non-integrated course taught only by an engineering professor. Both options use problem-based learning.	Students enrolled in the integrated course showed greater motivation and engagement in self-regulated learning strategies throughout the term compared to their peers in the non-integrated course. Additionally, these students reported more frequent use of critical thinking skills in their assignments, exhibited higher self-efficacy, and placed greater value on their learning tasks than those in the traditional course setup.

Source: authors

- Improved communication skills.
- Improved insight into practical aspects of workplace engineering.
- Improved multidisciplinary teamwork.
- Improved employment opportunities.
- Increased positive attitude toward the engineering course.
- Increased confidence in performing in the course.
- Improved team dynamics.

Benefits observed in recent studies confirm the importance of the recommendations made by entities such as the National Academies of Sciences, Engineering, and Medicine. Reports, such as that of the Royal Academy of Engineering, reinforce these recommendations by highlighting that future engineers will increasingly need ethical competencies and global responsibility acquired through the humanities to deal with today's complex challenges of the future.[23] In addition, Staley and Bairaktarova, through a conceptual review and analysis of curricula of educational institutions, showed that engineers trained under interdisciplinary curricular approaches perform better in interpersonal skills, intercultural communication, and ethical reasoning, being better prepared for the current challenges of the professional market.[24]

Conclusion

In conclusion, this article has explored the vital integration of humanities into engineering education, emphasizing its significance in cultivating engineers equipped for the challenges of engineering and technological innovation principles. This interdisciplinary approach not only enriches the curriculum but also ensures that future engineers are better prepared to deliver solutions that are not only innovative but also socially responsible and sustainable. The results demonstrate that the integration of the humanities in engineering education promotes fundamental competencies for the twenty-first century, such as empathy, communication, and complex problem-solving, in addition to preparing engineers to face global challenges with ethical and social responsibility.

The discussion highlighted that incorporating humanities broadens engineers' perspectives, enabling them to understand and apply ethical considerations and cultural insights into their professional practices. This holistic approach significantly improves the quality of technological innovations by ensuring they meet ethical standards and societal needs, aligning with the core principles of ESG.

Moreover, the article has shown that engineering education, enriched by humanities, fosters a deeper understanding of social impacts and enhances critical thinking, empathy, and ethical reasoning among engineering students. These qualities are indispensable for leaders who aim to implement sustainable and equitable solutions in an increasingly complex global landscape.

As technological advancements continue to transform our world, the role of quality engineering becomes ever more critical, ensuring that products and systems are designed and built to meet specified standards and are safe, reliable, and efficient. By integrating humanities, engineers gain the tools to critically assess the societal implications of their projects, ensuring that innovation not only is technologically sound but also enhances quality of life and sustainability.

In summary, the fusion of engineering with humanities is not merely an educational enhancement but also a necessity for developing engineers who can navigate the complexities of modern challenges with a responsible and informed approach. This paradigm shift in education fosters not only technical proficiency but also a commitment to ethical practices and social responsibility, essential for the sustainable development of our global society. By rethinking engineering education in an interdisciplinary way, we train professionals capable of balancing technical skills with a deeper understanding of the social and cultural implications of their actions and incorporating critical thinking as a core element; engineering education can better prepare students to address societal challenges with creativity, empathy, and responsibility, ensuring they become innovative problem-solvers.

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