



# Electromechanical projects in Higher Education: a transdisciplinary approach

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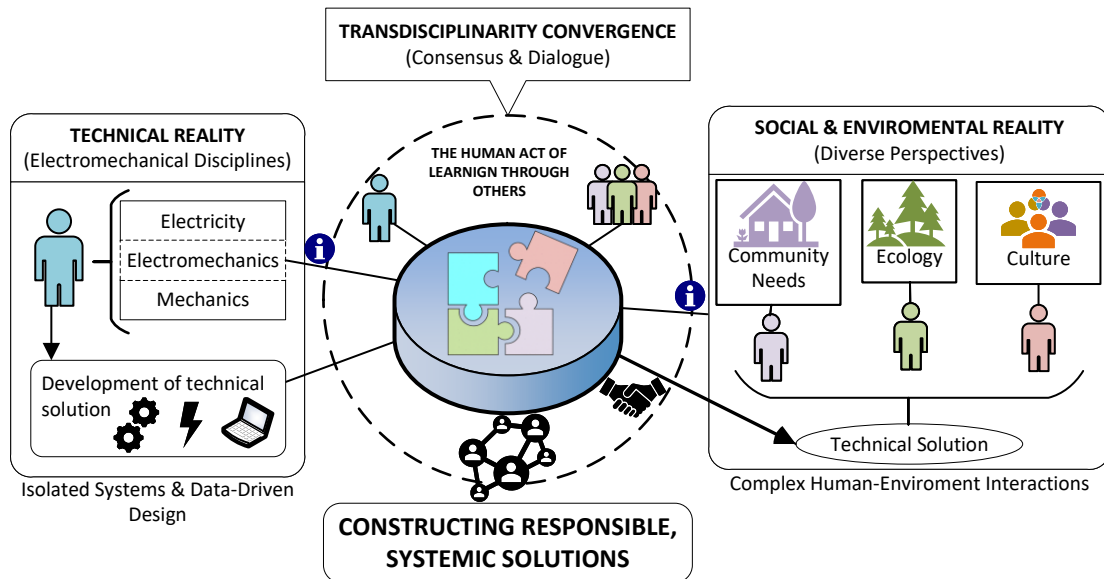
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**Abstract:** Electromechanical Engineering Projects in Higher Education (EEPHE) usually arise from an industrial need. Students analyze the problem and design a technical solution that meets that need, aiming to achieve a good grade in the subject or their degree. An analysis of nine EEPHE was conducted, identifying the type of wicked problem to which they contributed and the main disciplinary subjects involved. Different transdisciplinary methodologies used were also identified. This work seeks to provide a first approach and complement to transdisciplinarity for the development of university engineering projects, using a methodological proposal. Students will move beyond just creating a cool gadget. They will be pushed to develop meaningful, responsible, and socially-aware electromechanical solutions that truly address the ontological complexity of real-world problems.

**Keywords:** Engineering Education, Wicked Problems, Social Responsibility, Project-Based Learning (PBL)

# 1 Introduction

We understand transdisciplinarity as the human act of learning how the world works through others' perspectives. And agreeing on how to help build the convergence of realities with those we share. Being more academically rigorous: transdisciplinarity in engineering is the human act of understanding how the world works by integrating the perspectives of various actors to reach agreement on responsible electromechanical solutions. This involves building a convergence between technical and social realities, allowing the project to transcend the artefact and systematically solve the complex nature of real problems (see Figure 1).



**Figure 1:** Transdisciplinary approach.

The increasing complexity of modern global challenges necessitates a shift in engineering education, moving beyond traditional disciplinary boundaries to foster innovative problem-solving capabilities in students (Ertas et al., 2003; Jamieson et al., 2022; Wang & Kajfez, 2025). Croonin 2008, quoted by Ertas (2016), expressed the need for a Transdisciplinary Research (TR) when knowledge about a societally relevant problem field is uncertain (constitutive uncertainty), when the concrete nature of problems is disputed, and when there is a great deal at stake for those concerned by problems and involved in dealing with them. TR deals with problem fields in such a way that it can: grasp the complexity of problems, take into account the diversity of life world and scientific perceptions of problems, link abstract and case specific knowledge and constitute knowledge and practices that promote what is conceived to be the common good.

Electromechanical projects, which inherently integrate mechanical, electrical, computer, and control engineering with software and information technology, serve as a prime example of this complexity in higher education (G. Pop & Maties, 2011; Ledoux & Slaboch, 2025). To effectively address these multifaceted problems, a transdisciplinary approach is crucial, emphasising knowledge integration that transcends the limits of single disciplines and involves broader societal engagement (G. Pop & Maties, 2011; Lam et al., 2022; Wang & Kajfez, 2025).

This approach prepares students for professional environments where collaboration across diverse fields is essential for designing smart, flexible, and multifunctional solutions and systems (Pop & Maties, 2011; Jamieson et al., 2022). Organisations like The Academy of Transdisciplinary Learning and Advanced Studies (ATLAS) actively contribute to this paradigm by developing transdisciplinary tools, educational

materials, and programs for engineers, helping to bridge academia with industry needs and promoting a comprehensive understanding of complex issues (Ertas et al., 2023; Moran et al., 2021).

Transdisciplinary (TD) work questions the very foundations of traditional disciplinary thought, aiming to construct fresh methodologies from the ground up by repurposing elements from established academic fields, including a contextual moral and ethical (Bernstein, 2015).

TD generally rejects the separation and distribution of academic subjects and approaches into disciplinary ‘silos’ (Choi & Pak, 2006), however, this work intends that this TD and systemic approach converges to guide the development of university projects in the electromechanical area in order to formulate holistic projects with a social impact.

TD has been approached from contrasting perspectives that reflect both philosophical aspirations and practical demands. Two of the most influential approaches come from the Nicolescuian and Zurich schools (Bernstein, 2015). While the former, led by Basarab Nicolescu, proposes a profound ontological and epistemological vision based on levels of reality, the logic of the included third party, and the integration of scientific, spiritual, and artistic knowledge, the latter adopts a pragmatic approach focused on the collaborative resolution of complex real-world problems. The Zurich school, based at institutions such as ETH Zurich, prioritises co-creation of knowledge with social actors and the implementation of sustainable solutions, with an emphasis on governance, participation, and applied interdisciplinarity. Thus, both currents represent not only different ways of conceiving knowledge but also divergent paths towards integrating knowledge and action. The present work has a frame of reference and inspiration, ‘Transdisciplinary Methodological Option for Initial Research Process’ (Hernandez-Aguilar, 2018), As a result of this methodology and as a problem solver, the authors propose to develop an option to guide university students in this approach and contribute to the development of their critical thinking, also integrating elements of the Zurich school.

Beyond the integration of mechanical and electrical systems, Electromechanical Engineering Projects in Higher Education (EEPHE) must adopt a transdisciplinary framework (CIRET, 2020) By engaging multiple disciplines and stakeholders, EEPHE can transcend purely technical objectives to deliver comprehensive solutions that respond to complex social challenges.

The aim of this article is to provide a methodological alternative for developing electromechanical projects in a higher education context that takes into account social engagement and the co-production of knowledge (Zurich approach), the emergence of novel knowledge (Nicolescu approach), and transdisciplinary and engineering tools and sources.

## 1.1 Wicked problems

When is a problem classified as a Wicked Problem (WP)?

According to Rittel and Webber (1973), pare inherently distinct from the problems typically handled by scientists and certain types of engineers. Planning problems, especially those involving social or public policy, are intrinsically complex and challenging. The term ‘wicked’ is used in a sense similar to ‘malignant’ (as opposed to ‘benign’), “vicious” (as in a vicious circle), or ‘aggressive’ (as in a lion, as opposed to the docility of a lamb), not because their properties are ethically deplorable.

The problems that scientists and engineers have addressed are often ‘tame’ or ‘benign,’ for which the mission is clear, and it is clear whether or not they have been solved (such as solving a mathematical equation or achieving checkmate in chess). In contrast, WP lacks these clarifying features and includes almost all public policy issues. Rittel and Webber identified at least ten distinctive properties of planning (i.e., wicked) problems: There is no definitive formulation of a wicked problem, Wicked problem have no stopping rule, Solutions to WP are not true or false, but good or bad, There is no immediate or definitive proof of a solution to a perverse problem, Every solution to a wicked problem is a one-shot operation; because there is no opportunity to learn by trial and error, every attempt counts significantly, Wicked problem do not have an enumerable (or exhaustively describable) set of potential solutions, nor a well-described set of permissible operations that can be incorporated into the plan, Every wicked problem is essentially unique. Every perverse problem can be considered a symptom of another problem. The

existence of a discrepancy that represents a wicked problem can be explained in numerous ways. The choice of explanation determines the nature of the solution to the problem. The planner has no right to make mistakes.

Oliván-Cortés (2021) lists and illustrates characteristics of WP, such as: No clear definition, Problems are unique, Interdependencies and multicausal, Sit astride organizational boundaries, Problems have no end, Seemingly intractable with chronic policy failure, Are never completely solved, The problems come into conflict, Need time to think about them, Solutions branch out, Unknown consequences, Solutions are not right/wrong, Solutions are better/worse. There are several examples, including but not limited to climate change, obesity, poverty, plastic waste, the COVID-19 pandemic, refugee crises, structural unemployment, involuntary loneliness, access to clean water, gender-based violence, and inequality.

However, Alford and Head (2017) have done a deep work on what a wicked problem. They propose a typology of WP (Figure 2) and wrote about strategies for tackling it.

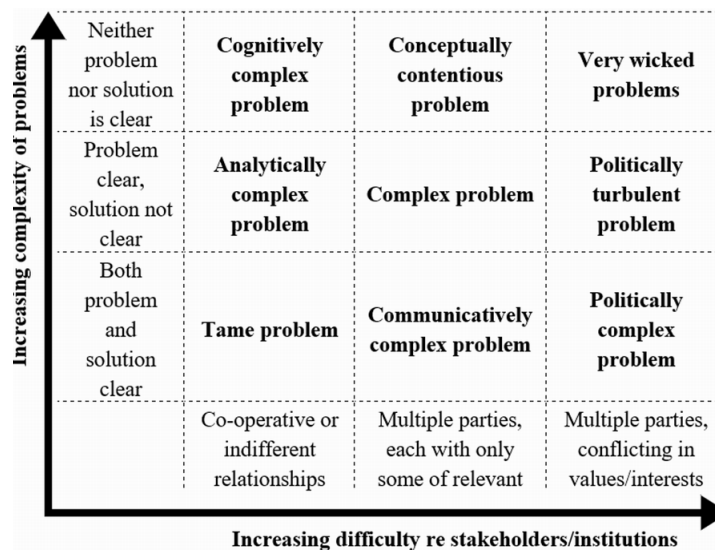


Figure 2: Alternative types of complex problems (Alford & Head, 2017).

Especially helpful is the two-dimensional typology based on the two irreducible elements of the wicked problem: the problem to be addressed and the actors (stakeholders). The vertical axis ranges from a trivial problem with a known solution, when the solution does not increase the problem’s complexity, to an unknown problem with an unknown solution, when the problem’s complexity is maximal according to the matrix. The horizontal axis represents the increasing difficulty for stakeholders/institutions (the means of solving the problem). Cooperative or indifferent relationships between stakeholders/institutions mean there is a low or null level of relation, an increment of difficulty in re stakeholders/institutions means there are multiple parties, each with only some of the relevant information, and finally, the most difficult relationships are multiple parties, conflicting in values or interests. These two together determine the exact kind of complex problem.

The methodological proposal aims to complement the development of technical solutions that help address these complex problems in the technical field, thereby contributing to their resolution. In the same way, recognizing the type of complex problem is essential in the methodological proposal.

Their importance lies in the new role of the professor, advisor, or educator in education and development projects with social impact. Galaz Fontes and Gil Antón (2009) reflect on the direction of the academic profession over the years. Traditionally, professionalization, based on modern science, conceived each profession as a subset of engineering, whose scientific knowledge was applied to solve problems. However, social and public policy problems are inherently different from the “tame” problems that classical science and engineering solved.

## 2 Electromechanical projects

### 2.1 Differences between Electromechanics and Mechatronics.

Mechatronics takes an approach that integrates mechanics, electronics, and computing (information technology) to create intelligent, automated systems (Berian & Maties, 2011), unlike Electromechanics, which focuses on combining and coupling electrical and mechanical systems for the design and maintenance of machines and devices; in authors experience. The purpose of the first is to design, develop, and optimize automatic systems and robots that respond to environmental stimuli, seeking efficiency, flexibility, and precision. The second aims to design, install, and maintain power systems, industrial machinery, and components that use mechanical force driven by electrical energy. The difference is relevant to the authors, but it is considered impossible to name one without including the other. Craig (2021) has been developing mechatronics projects since 1995 and created the iconic mechatronics diagram to illustrate this multidisciplinary field, where we can see a Venn diagram composed of four systems: control systems, computers, electronic systems, and mechanical systems, where the convergence of all is called mechatronics in the same way convergence mechanics and electricity define Electromechanical.

As well, he did it in mechatronics; our current perspective on electromechanical knowledge could be reflected in (Figure 3). The geographical, temporal, cultural, and academic contexts may lead the authors to conflate electromechanics with mechatronics, which is why we previously defined the disciplinary boundaries of each discipline. However, they are very similar. And in practice, they are. For this reason, throughout this document, we will consult the transdisciplinary frame of reference for projects developed in higher education or universities in the field of mechatronics, as well as for various engineering projects.

### 2.2 Transdisciplinary approach to higher education

Texas Tech University has a TD master of engineering program developed by the Institute for Design and Advanced Technology (IDEATE) (Ertas et al., 2003). Drawing on five SDPS workshops (1996–2001) and the cruise control system (ECCS) case, they show that teams limited to a single discipline produce suboptimal solutions, whereas collaboration yields superior designs. The authors describe a pilot Master of Engineering program at Texas Tech's IDEATE, built around four core courses (process, systems, metrics, and a track) and co-designed with Raytheon. The study concludes that transdisciplinary education balances holism and reductionism, enhances research quality, and aligns graduate training with industry needs. This methodological proposal aims to be a first step towards developing electromechanical projects using a transdisciplinary approach and, consequently, to lay the foundations for a specialisation programme in transdisciplinarity, as Texas Tech University has done.

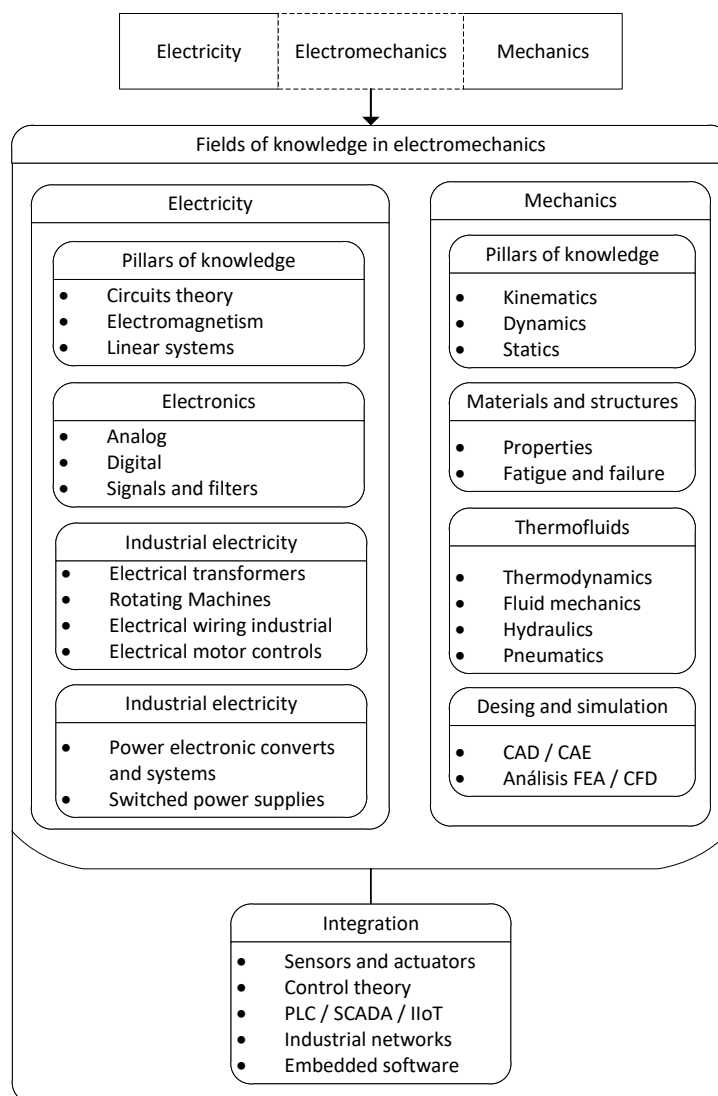
In the same way, the University of Alberta successfully incorporated in 2020 a TD course, "Introduction to Engineering Design, Communication and Profession," for 1200+ first-year students. This achievement is a common transdisciplinary process across engineering programs; sustainability was embedded as a key societal goal in the project (Jamieson et al., 2022).

On the other hand, the University of the Basque Country (UPV/EHU) integrates Sustainable Development Goals (SDGs) into the Electrical Engineering degree via transdisciplinary Capstone Projects, aligning with the university's 2030 agenda program (Aginako et al., 2021). The core objective is to update the curriculum to reflect modern shifts in electrical engineering, leveraging sustainability as a change engine. A working team, comprising faculty from business organizations and electrical engineering, a technical architect, and students, executed this intervention. Two specific projects were conducted at the Leioa campus, both focused on reducing electrical power consumption: designing a smart electrical microgrid and redesigning outdoor lighting in accordance with energy-efficiency criteria. This collaborative, reality-linked approach uses the campus as an experimentation area to promote sustainability literacy institutionally.

Another case of application of the TD approach on higher education is the Centre for LifeLong Learning and Design (L3D) at the University of Colorado Boulder (Center for LifeLong Learning & Design, 2026). They contend that most pressing social and scientific problems (such as energy sustainability or smart

grids) are between and beyond specific disciplines. These WP require a move from multidisciplinary (loose cooperation) and interdisciplinary (blending ideas) to a transdisciplinary approach that transcends specific disciplines to define new knowledge at their borders. Also argues that higher education must shift from a consumer culture of learning to a culture of participation. This involves fostering specific transdisciplinary competencies in students, including:

- Problem Framing vs. Problem Solving: Integrating the initial definition of a problem with the creation of its technical solution.
- Boundary Crossing: Developing the knowledge and skills required to identify and address problems that cut across traditional academic silos.
- Collaborative Knowledge Construction: Learning to communicate and work with people from different disciplines, educational levels, and even stakeholders from outside the academy.



**Figure 3:** Author’s interpretation of electromechanics and holistic vision between these fields.

As a consequence, L3D bridges the gap between technical design and social impact by designing socio-technical systems. Their approach emphasizes that education should not be a separate phase of life but integrated into real-world problem-solving and creating social and technical infrastructures where users can choose to become designers, thereby empowering problem owners rather than just providing them with finished tools. The center put this thesis into practice in a program called Undergraduate Research and Apprenticeship Program (URAP), creating teams that are interdisciplinary by nature and transdisciplinary in practice by vertically integrating undergraduate apprentices, PhD students, faculty members, and industry partners working on personally meaningful problems. L3D argues that by embracing ideas such as cultures of participation and the symmetry of ignorance (nobody has all the answers to a complex problem), transdisciplinary education empowers citizen-scholars to thrive in a collaborative and ever-changing world.

Derry and Ficher (2006) presented a document based on a meeting of the American Educational Research Association (AERA) Symposium “Socio-technical Design for Lifelong Learning: A Crucial Role for Graduate Education”, in which they summarised their ideas and models regarding the necessity of TD in graduate education. The approach they describe is grounded in the following proposition: *“If the world of working and living relies on collaboration, creativity, definition and framing of problems and if it requires dealing with uncertainty, change, and intelligence that is distributed across cultures, disciplines, and tools—then graduate programs should foster transdisciplinary competencies that prepare students for having meaningful and productive lives in such a world.”*

In the same vein, Pop and Maties (2009) present a TD view of mechatronics, tracing its evolution from 1969’s mechanical-electrical fusion to 1996’s academic legitimization as a synergistic integration of mechanics, electronics, and intelligent control. They consider mechatronics as a transdisciplinary educational paradigm that goes beyond a simple combination of mechanics, electronics, and control, emphasizing a reflexive communication logic and a socio-interactive context of thinking, living, and acting. Sustainable products and a new generation of mechatronics require this transdisciplinary paradigm (Pop & Maties, 2011).

Berian and Maties (2011) proposed a hexagonal model for integral mechatronic education, emphasizing concurrent engineering, systemic thinking, and the balance of formal and functional legitimacy. The conclusion stresses that only a transdisciplinary, complexity-centric approach can sustain mechatronics’ future relevance and innovation. Similarly, we are working on electromechanical projects under our responsibility.

The works we consider most noteworthy for the methodological proposal we present, and which the authors hope to implement in the coming years at our university, are Ford and Ertas (2024) and Ertas’ (2016) proposal for the development of a doctoral programme and curriculum based on Nicolae’s approach. The present work is a step towards achieving this goal for formalising transdisciplinary programs at Tecnológico de Estudios Superiores de Chalco.

Unlike Nicolae’s approach, which seeks unity of knowledge, the Zurich School focuses on solving problems in the “life-world” (Pohl & Hirsch Hadorn, 2008). For them, DT is a collaborative design practice involving non-academic actors (Hadorn et al., 2008). This approach is also considered with a contribution to the methodological proposal.

## 2.3 Analysis of university electromechanical and mechatronic projects

Usually, EEPHE does not cover all fields of electromechanics when developing a project, although there are often interdisciplinary contributions (Table 1). This section of the document analyzes examples from the electromechanical university engineer projects that also involve transdisciplinarity and identifies the type of complex problem being addressed.

While the ASME vehicle project (Bernat et al., 2024) serves as a well-documented example of the engineering process within a university context, its scope is primarily technical; although stakeholders and purposes are clearly defined, the social impact is limited as the project functions mainly as a platform for students to test their individual abilities.

**Table 1:** *Examples of Electromechanical Projects in Higher Education. Note: M: Mechanics, E: Electricity, EL: Electronics, B: Bionic, CS: Computer Science, H: Hydraulics, Me: Medicine.*

Short project name	Type of wicked problem addressed	Duration	Primary Disciplines Integrated	Reference
ASME vehicle	Analytically complex	One year	E, M	(Bernat et al., 2024)
Actuator design	Tamed	Does not specify	M, E	(Sleight Crawford et al., 2023)
Bionic limb design	Complex	Two years	M, E, B, CS	(Lam et al., 2022)
Design of temporary refugee housing	Very complex problem	Does not specify	CS, M	(Moran et al., 2021)
Hydroturbines Design	Tame	Does not specify	M, A, H, CS	(Pomesky et al., 2025)
ENGR 1320	Complex	Two years	Bio-engineering	(Carrell & Hailu, 2024)
IE 4331: Biomedical Innovation	Very complex Problem	One Year	Me, B	(Tan et al., 2022)
Separating the stages of mealworm production	Communicatively complex	Does not specify	EL, M, CS	(St-Pierre et al., 2023)
Cleaning and sorting machine	Communicatively complex	One year	M, E	(López-Almonte, 2025)

While the ASME vehicle project (Bernat et al., 2024) serves as a well-documented example of the engineering process within a university context, its scope is primarily technical; although stakeholders and purposes are clearly defined, the social impact is limited as the project functions mainly as a platform for students to test their individual abilities.

In contrast, the Carrell and Hailu project (2024) moves toward a truly transdisciplinary approach by centering on a shared, authentic problem that links four core bio-engineering subjects over two years of study. This methodology is further formalized and deepened in the ENGR 1320 Bioinspired Design for Engineers course, which demonstrates a transdisciplinary model by embedding biology directly into the engineering curriculum. By requiring students to observe natural systems, extract biological principles, and translate them into engineering solutions, the course merges the disciplinary languages and mindsets of both fields.

Learning outcomes in this model explicitly target both domains: understanding biological mechanisms and analogizing them to engineering functions, through team-based design projects and prototypes. As a result, student reflections show that this interdisciplinary exposure reshapes their perception of nature as a source of inspiration, fostering a cross-disciplinary curiosity. Ultimately, as noted by external observers, the Biomimicry Thinking framework provides a structured problem-solving process that extends beyond traditional engineering methods, aligns with ABET criteria, and enhances critical systems thinking across domains.

An interesting case of applying transdisciplinary in higher education is found in Texas Tech University's IE 4331: Biomedical Innovation course (Tan et al., 2022). This initiative transcends traditional academic silos by pairing engineering undergraduates with first-year medical students to navigate the complexities of the biopharma and medical-device markets. This course embodies a transdisciplinary approach by moving

beyond simple interdisciplinarity; it creates a culture of participation where different levels of reality, the technical engineering space, and the clinical medical environment must converge. Following the Zurich school of thought, the curriculum focuses on solving life-world problems through a two-semester cycle of problem identification and prototyping. Students are forced into the "human act of learning through the perspective of others," where engineers must internalize clinical constraints and medical students must grasp technical feasibility to achieve a unified solution.

According to the complexity matrix, the projects addressed in IE 4331 are categorized as very wicked problems. In the \$1.3 trillion biopharma and \$156 billion medical-device markets, often neither the problem nor the solution is clear at the outset, and respecting stakeholders, these projects involve multiple parties with conflicting values and interests, including regulatory bodies, the Food and Drug Administration (FDA), healthcare providers, insurance payers, and patients.

By tackling these wicked challenges, the course moves students beyond creating "cool gadgets" and pushes them toward socially aware, systemic solutions. The significant gains in self-efficacy, particularly in technical evaluation (1.41-point increase), demonstrate that operating within this transdisciplinary hidden third strengthens the research and communication skills necessary for the 21st-century workforce.

In the entotechnology area, students from the Department of Bioresource Engineering designed a novel low-cost mechanical system to separate *Tenebrio molitor* life stages for TriCycle Inc., a company that rears mealworms on local food residues (St-Pierre et al., 2023). They expressed concern that separating mealworm life stages in their industrial operation is crucial, as yellow mealworms can exhibit cannibalistic behavior toward less active stages, namely pupae and eggs. In the same disciplinary field, López-Almonte (2025) developed a sorting machine to support local edible insect farmers, mechanizing sorting and cleaning operations. This stems from the same need for a company to mechanize the unit operations of cleaning and sorting larvae at different stages. However, without the technology, the tasks were performed manually, leading to the dehumanization of those who spent hours cleaning larvae. Due to Electromechanical engineering students with no knowledge of entomology or insect breeding visiting the company and immersing themselves in the process, meeting people who spend hours cleaning and sorting larvae for the breeding process, and developing a sorting machine that helps to develop this sustainable industry based on waste recovery.

The Hydroturbines capstone, led by Alex Pomesky, brings together mechanical-fluid design, electrical control, instrumentation, and data analysis in a single student project. By requiring a turbine, a hydraulic test bench, an Arduino-based control system, and sensor integration, the work forces students to apply concepts from several engineering domains simultaneously; exactly the "application of theories, concepts, or methods across disciplines" that defines transdisciplinarity.

However, transdisciplinarity is not limited to the merging of hardware and software; it also encompasses human systems. This is evidenced in the project by Crawford et al. (2023), which shifts the focus from purely technical efficiency toward a deeper integration of knowledge that transcends traditional engineering. The project of Crawford et al. (2023) linked to transdisciplinarity by using highly complex technical projects as a basis for a deeper integration of knowledge that transcends traditional engineering. While the conventional model focuses on solving industrial demands through technical efficiency and the creation of sophisticated devices, the proposed approach seeks to expand these limits by incorporating the vision of various stakeholders and ethical-social dimensions. In this way, electromechanical development ceases to be solely an exercise in functional optimisation and becomes a holistic and responsible response to real-world problems, aligning itself with global objectives of sustainability and social commitment.

In contrast, the project of Pomesky et al. (2025) also tackles a sustainability-driven, real-world problem (renewable energy generation) and is framed as a community-based engineering challenge, matching the four guiding principles of the University of Alberta's transdisciplinary first-year course: design as a core feature, a common transdisciplinary process, sustainability as a societal goal, and communication of the evaluated proposition. Because the students must coordinate team roles, document their work, and present results, the learning environment mirrors professional interdisciplinary teams, reinforcing the "transdisciplinary learning environment" that better represents actual engineering practice.

Regarding transdisciplinary methodologies, several convergent approaches can be implemented by mechatronics and electromechanical engineering students to develop projects that foster a meaningful social impact (Bacilio et al., 2016; Berian & Maties, 2011; Cuellar et al., 2013; Ertas, 2016; Rincón Pardo & Narváez Tovar, 2024; Salas-Ramírez, 2024). Similarly, the strategy applied by Tecnológico de Monterrey in Mexico, where university students must develop technology-based products in two courses, in addition to describing this process, describes these activities in a flowchart, and the authors consider this type of source to be useful and innovative (Esqueda Merino et al., 2019).

Among the most noteworthy works is that of Phan and Ngo (2020), which is noteworthy due to its in-depth treatment of the subject and its addressing of issues such as the lack of resources when carrying out university projects, as well as the expansion of social awareness.

As a frame of reference and due to its inclusion in the transdisciplinary process, we include the work of Moran et al. (2021). Although it is not related to university projects, its methodology stands out for providing and exemplifying the use of engineering methods and tools in the design of temporary refugee housing.

Expanding this scope toward large-scale systemic solutions, the work of Moran et al. (2021) offers an extraordinary contribution to engineering transdisciplinarity. While not strictly an electromechanical university project, it is included for its sophisticated application of Integrated Transdisciplinary Tools (ITDT) to solve a complex humanitarian crisis. The study presents a TD design process for refugee housing, integrating Kano analysis, TRIZ, and Axiomatic Design (AD) to resolve engineering contradictions, such as material weight versus strength, resulting in a housing solution capable of addressing the needs of 50 million displaced persons.

## 2.4 Multidisciplinary, Interdisciplinary, or Transdisciplinary

The authors consider this brief section important, as they view this article as an initial introduction for readers before starting with the methodological proposal. Like mechatronics, electromechanics must define five stages of knowledge-process: monodisciplinary, co-disciplinary, multidisciplinary, transdisciplinary, and transdisciplinary electromechanics (Pop & Maties, 2009). Electromechanics cannot be reduced to a single convergence of mechanical and electrical knowledge, but rather considered a transdisciplinary, socio-interactive electromechanics with social impact.

Multidisciplinary represents the primary level of integration where various fields address specific facets of a shared problem independently (Wang & Kajfez, 2025). In engineering, this involves coordinating different branches, such as mechanical or electrical, while remaining strictly within the traditional boundaries of the technical domain. Interdisciplinarity is a research approach applied in the search for answers to questions for which a single discipline is not sufficient (Di Giulio & Defila, 2024). Transdisciplinarity, on the other hand, is an approach that allows for the investigation of issues that cannot be adequately addressed based solely on academic knowledge systems. There is an excellent graphical representation of kinds of disciplinary approaches (Mono-disciplinarity, Multi-disciplinary, Cross-disciplinarity, Inter-disciplinary, and Transdisciplinary) from Rousseau et al. (2018, p. 53), consulting for more information.

## 3 Proposal Methodological

Six stages are proposed for the development of EEPHE under a transdisciplinary approach, the stages are:

1. Problem Framing and Stakeholder Integration
2. Work plan
3. Conceptual analysis
4. Detailed design
5. Construction
6. Technical and transdisciplinary evaluation

### 3.1 Problem diagnostic and reality perspectives

Why start with Context Analysis? Because the only constant in the universe is change, the formulas, theories, and mathematics governing the laws of the universe, as well as the disciplinary knowledge developed so far, remain the same; hence, the phrase ‘on the shoulders of giants’ is used to allude to using the disciplinary knowledge acquired by the leading thinkers to make intellectual progress. Students need to be connected with their reality and consider the multidimensional context and their WP. Nicolescu B. (2012) stresses the need to apply transdisciplinarity as a complement to disciplinary knowledge, and the important role of universities as actors that can enable sustainable and human development. Identifying the Hidden Third is perhaps the most challenging yet rewarding part of transdisciplinary training. In the Nicolescuian sense, the *Hidden Third* is not a physical component you can touch; it is the mediator that exists between the Subject (the student, the community, the researcher) and the Object (the electromechanical system, the technical problem).

To help students "see" what is invisible, we must move them through a pedagogical process of Ontological Shifting. AoE has the task of finding the right activity to achieve it.

#### 3.1.1 Awareness of the current situation

To increase awareness of their reality, students must carry out a multidimensional contextual analysis that includes at least the following dimensions: Cultural: values, beliefs, customs, and ways of life specific to their environment. Temporal: historical evolution and changes over time that have shaped their present. Geographical: characteristics of the place (climate, landscape, infrastructure, natural resources). Religious: belief systems, rituals, and their influence on morals and social practices. Economic: production structures, distribution of wealth, and level of development. Social: relationship networks, norms, roles, and power dynamics within the community. Linguistic: the language or dialects they speak and how they condition communication and thought. Educational: access, quality, and focus of the education systems they have received. Demographic: composition by age, gender, population density, and migration. Ethnic: ethnic roots and diversity, collective identities and processes of inclusion/exclusion. Aesthetic: artistic and symbolic expressions and their perception of beauty in the environment. By examining each of these dimensions, students gain a holistic view of their current situation and the factors that shape it.

As a result of these activities, students could generate sketch notes, photo essays, audio logs, collages, or a report, the main goal being to have hard data about the context. This useful information is crucial as a starting point.

#### 3.1.2 Self-knowledge and transdisciplinary attitude

The advisor or educator (AoE) is a guide not only on this path, however need to determine the optimal activities and tool to use and which encourage the students to get the goal and finish the project on time, and so far, there is no device to measure transdisciplinary attitude, so determining whether students have understood the meaning of transdisciplinarity is a complex task. Therefore, we like to start the approach with an ambiguous question: ‘How does the world work for me?’ There are numerous possible answers, and these could be useful for the AoE as a starting point for determining what activities to design and propose to the student to foster their transdisciplinary attitude.

A Rounder Sense of Purpose Project (RSP Project, n.d.) suggests some activities for students with the aim of learning about transdisciplinarity. However, if students do not have a first approach to TD, the recommendation is that before starting any activity, they read the Charte de la Transdisciplinarité (CIRET, 2020) aloud in a group, then discuss the points and clear any questions. Which activities are recommended for teaching transdisciplinarity? When is it recommended to do it?... all depends, depends on what? As an AoE, it depends on the obstacle or hurdle; there are different methods and tools that could help us. In the same way, SCANAT (n.d.) collected useful methods to be used in different contexts or stages of knowledge co-production and showed them classified by phases.

### 3.1.3 Chose a twisted/wicked problem

Once students have a conscious understanding of their reality, they can propose some alternative projects in which they can apply their knowledge of electromechanics to solve these WP as a one piece of the puzzle.

AoE can help students with this task. The selection must be justified, and it is possible to establish some selection criteria and a method to help them achieve this.

Some of the alternatives recommended by the authors are: as criteria, consider first the nature of the problem, the integration of perspectives, and the actual feasibility of the project (see Figure 2). However, in some cases, criteria such as the student's motivation to develop the project, lack of specific disciplinary knowledge, difficulty in obtaining specific construction materials, or the unavailability of stakeholders could be acceptable; see Figure 1 for more examples.

It is essential to have a holistic view of the problem, just as the information obtained from stakeholders is crucial, so multiple interviews and site visits may be the best way to obtain all the information needed to make the best decision.

**Table 2:** *Example of a practical evaluation rubric.*

Criterion Category	Guiding Question	Score (1-5) & Justification
Problem Significance	How deeply does this problem affect a real community, and how complex are its interconnected causes?	Example: Score 5. The lack of accessible public transport for elderly in our city's periphery is a well-documented issue leading to social isolation (social) and health decline (human).
Transdisciplinary Integration	How genuinely will we involve diverse stakeholders and blend different types of knowledge (not just technical)?	Example: Score 4. We plan workshops with elderly citizens, city planners, and bus drivers. We will also consult a sociologist to understand the social dynamics of isolation.
Feasibility & Ethics	Can we build a meaningful prototype, and have we considered the unintended negative consequences of our solution?	Example: Score 4. Our prototype will be a smart-bus-stop interface. We've considered data privacy for users and will use open-source hardware to keep costs low for the city.

In Table 2, evaluate the human-centered impact. Where 1 means less significant score and 5 very significant. The proposal should clearly identify who is affected and how. Can the students show that the problem isn't just a technical glitch but is tangled with social, economic, environmental, and/or political factors? They should map out these connections (rich view of the system). A good wicked problem has multiple stakeholders with different values and priorities. The proposal should acknowledge these conflicting viewpoints and explain why a simple technical fix would fail. Also, stakeholder engagement is contemplated. Does the proposal include a clear plan to actively involve non-academics (like community members, local government, industry partners, NGOs) throughout the project, from defining the problem to testing the solution? It's not enough to just ask for their opinion at the end. Another useful question is: How will the project merge knowledge from different fields? It should go beyond just electrical and mechanical engineering. The proposal needs to specify how it will incorporate insights from social sciences, design, economics, or even the arts to create a more holistic solution, and do not forget the system perspective: Does the proposal analyze the problem as a whole system? It should consider potential unintended consequences. For example, will an automated solution displace workers? Will a new device create electronic waste? The team should show they've thought about the ripple effects. The last file of the table focuses in practicality

and responsibility of the proposed project. Is the proposed electromechanical device or system achievable within the timeframe and resources of a university project? The proposal should define a clear, manageable scope for a prototype or pilot (minimum viable product), while also thinking about how it could be scaled up in the future, or has the team proactively identified potential ethical issues? This includes data privacy, accessibility for people with disabilities, environmental impact, and social equity. They should propose strategies to mitigate these risks. About sustainable and adaptable design, the proposed solution shouldn't be a "black box." It should be designed to be adaptable, repairable, and sustainable. The proposal could discuss material choices, energy consumption, and plans for long-term maintenance. So, the alternative with the highest score should be the best choice.

### 3.2 Work Plan

Electromechanical projects in universities have different duration periods, fourteen weeks (Craig, 2021), six months, one or two years, to name a few. It depends on the course, signature, university, and country. The framework here starts with the Technology Readiness Levels (TRL), which are used to manage technological development and are used as a systematic measurement tool. Their function is both to assess the degree of maturity of a technology and to consistently compare that degree of development with that of other technologies. An example of a two-year University Electromechanical Engineering Project (EEPHE) proposal (Table 3). Of course, this depends on the structure of the curriculum, as well as the length of the academic terms and the degree programme, and the fluidity of the development process.

**Table 3:** *Stages of methodological proposal duration and level of technology goal.*

Stage	Duration	TRL
1, 2	One semester	1
3, 4	One semester	2, 3
5	One semester	4
6	One semester	5

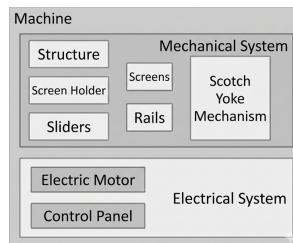
Consider scheduling meetings with stakeholders, mainly in phases three and four, to receive feedback and share the same vision of the technical solution; recall the nine papers of the letter on transdisciplinarity, as well as phase six, when transdisciplinary validation and evaluation are necessary.

### 3.3 Conceptual Analysis

What questions do we need to ask ourselves to determine the requirements of the system or technical solution? Before starting the conceptual analysis, conduct in-depth research on the state of the art to enrich the process.

In the Conceptual Analysis stage, the goal is to translate the complex, real-world problem into a holistic system view and a concrete set of technical requirements or design requirements. A key systemic tool for this is the creation of a graphical representation of holistic elements that constitute an electromechanical project.

Creating a holistic representation (see Figure 4) could help clarify the interactions with all the systems involved and their elements. At the same time, this graphical representation helps determine the requirements of the technical solution, taking into account all the stakeholders involved.



**Figure 4:** Holistic representation of elements that constitute a machine using a systemic approach.

Based on these well-defined requirements, the team can then make an informed selection of the most appropriate solution methods and development tools. The development of a University Electromechanical Project (UEP) typically requires a suite of integrated software tools:

- Computer-Aided Design (CAD): Essential for modeling the physical structure, mechanisms, and housings. Tools in this category (e.g., SolidWorks, Autodesk Fusion 360) allow for the virtual testing of fit, form, and function prior to manufacturing.
- Electronic Design Automation (EDA): Used for schematic capture of electronic circuits and the design of Printed Circuit Boards (PCBs) that will control the project (e.g., KiCad, Autodesk Eagle).
- Integrated Development Environments (IDEs): Necessary for writing, compiling, and debugging the firmware for microcontrollers. The choice of IDE (e.g., Arduino IDE, PlatformIO) is closely tied to the selected microcontroller hardware (e.g., Arduino, ESP32, Raspberry Pi).
- Simulation and Modeling Software: Critical for virtually testing control systems, mechanical dynamics, and electrical circuits. This allows teams to validate algorithms before implementing them on physical hardware (e.g., MATLAB/Simulink).
- Project Management and Documentation: Collaborative platforms (e.g., Github, Trello, Notion) are vital for managing tasks, version control, and documenting the design process, ensuring transparency and continuity within the team.

Be sure students select the available software on university facilities or the one agreed upon by the work group. Of course, some of these alternatives have a cost and must be considered in the first stage of the present methodological proposal, such as facilities and resources within reach or affordable.

A useful tool for the development of UEP is Theory and Innovative Problem Solving (TRIZ). This method is one of the most used by inventors and engineers (Ekmekci & Nebati, 2019). The AoE could recommend the use of this method, as well as Axiomatic Design (AD). There are numerous papers about the application of AD in different fields. However, Suh (1995) illustrates basic concepts using simple mechanical design examples.

### 3.4 Detailed Design

Drawing sketches is a start in design engineering; sharing them with the team could help define all the details and maintain the same vision of the technical solution.

Once the conceptual design has been completed, it is necessary to define and choose the materials with which the prototype will be manufactured. Some of this information is usually derived from calculations. On the other hand, a less sophisticated practice is to draw up a comparative table of desirable characteristics. Chemical: Density, Corrosion Resistance, Optical Clarity, Flammability, Porosity. Electrical: Electrical Conductivity and Dielectric Strength. Thermal: Specific Heat, Coefficient of Thermal Expansion, Thermal Conductivity, Melting Point. Or Mechanical, such as Hardness, Strength, Flexibility, Ductility, Toughness, Malleability, Brittleness, Stiffness, to name a few, and choose the best one according to the opinion of the stakeholders.

Draw plans of each piece that form the prototype, be specific and clear about their dimensions and shape, including different views: isometric, frontal, lateral, etc. Add title block for each part, which identifies the component or assembly; the part number, a unique identifier for the drawing; the revision level, which tracks changes and updates; the scale, indicating the ratio of the drawing size to the actual part size; and the drawing date, showing when the drawing was created or last revised, the designer's name, the material specification, and the units of measurement used. These elements ensure clear identification, traceability, and effective communication among the students' team. If the team considers relevant stakeholder feedback, add a note on the title block. On the other hand, for electrical and electronic diagrams, the recommendation is the same.

If there is a programming component on the technical solution, pseudocode and flowchart are essential tools at this stage, as well as the design of the Graphical User Interface (GUI) by sketches or conceptual ideas.

### 3.4.1 Digital Twins

A Digital Twin (DT) is a virtual representation of an object or system designed to accurately reflect its physical counterpart in real time (IBM, 2021). Its relevance in transdisciplinary engineering lies in the fact that the TD model not only replicates the machine, but also its behavior and evolution within a real ecosystem (social, energy, environmental). This allows students to anticipate non-technical (economic, ethical) consequences before physical construction (Crespi et al., 2023).

Engineering systems do not arise spontaneously; they progress through life cycle phases that include creation, production, operation, and disposal (Grieves & Vickers, 2016). Problems that lead to undesirable and unpredictable emergent behavior are established during the initial phases and manifest themselves in the operational phase. Many of these problems are attributable to human interaction and inherent complexity.

Therefore, we propose that TD integration, by continuously linking the physical system with its virtual equivalent, can mitigate these systemic problems. TD serves as a space for continuous simulation and validation to define and understand the project's behavior throughout its life cycle. This is fundamental to the Zurich School of Transdisciplinarity, as it turns DT into a tool for the co-creation of knowledge and ethical and responsible decision-making with stakeholders.

As a result of this stage, the students draw mechanical and electrical plans and simulate the behavior and operation of the technical solution.

## 3.5 Solution Development

At this stage, the EEPHE is ready to be built, representing what Mankins (1995) termed the "proof-of-concept"; this is the milestone that marks the transition from basic research to active research and development.

The AoE, in collaboration with the student team, must ensure all necessary resources are in place before construction of the EEPHE begins. These resources include materials, tools, and facilities. Furthermore, the scheduling of workshops and laboratories must be organized and agreed upon in advance by all team members.

The actual development involves the assembly and integration of all designed subsystems (e.g., mechanical structure, electrical components, and control unit) according to the finalized blueprints from the preceding stage. The student team is responsible for the hands-on construction, while the AoE provides technical oversight, troubleshooting support, and continuous quality assurance checks at key milestones to mitigate risks and ensure design specifications are met.

A functional prototype working under laboratory conditions is the result of this stage.

### 3.6 Technical and Transdisciplinary Evaluation

This final stage of development is designed to confirm the successful realization of the EEPHE prototype and to assess the efficacy of the transdisciplinary methodology.

#### 3.6.1 Technical Validation

The functional prototype is subjected to a rigorous testing program under laboratory conditions to validate its performance against the design requirements defined in stages 3 and 4. This evaluation includes the measurement of critical parameters such as power output, structural integrity, and the precision of the control unit. The successful completion of these tests ensures the technology has achieved a TRL of 4 or 5 (Component/System validation in a laboratory or relevant environment).

#### 3.6.2 Transdisciplinary Assessment

A parallel assessment is conducted to evaluate the effective integration of diverse knowledge fields (e.g., engineering sub-disciplines, environmental impact studies, etc.) throughout the design and construction process. This assessment focuses on analysing the quality of the trade-offs and the holistic solutions achieved by the team.

Klein (2008) describes seven generic principles that provide a coherent framework for thinking about transdisciplinary evaluation. We adapted to assess EEPHE:

1. Variability of goals. TD research is crucial for EEPHE that addresses wicked problems, and these projects are rarely driven by a single objective. Context sensitivity and flexibility are paramount for effective assessment. Project goals may be epistemological (e.g., producing novel, comprehensive knowledge of a system's failure mode) or strictly application-focused (e.g., developing a robust technical product, such as a specialized sensor, an IT protocol for smart grids, or a prototype energy storage device). The observed variety of technical objectives; ranging from predictive power, parsimony, feasibility, and operability to demonstrated impact on pragmatic problem-solving, directly necessitates a corresponding variability in quality criteria and indicators used for assessment.
2. Variability of criteria and indicators. Crucially, assessment must also include expanded indicators that capture the research's broader impact through outcomes in multiple fields, participation in new subfields, and the generation of novel policy initiatives or altered protocols. Assessing transdisciplinary research demands a flexible approach that moves beyond conventional metrics such as patents, publications, and prestige, which are often criticized for their narrow disciplinary focus. Effective evaluation must incorporate epistemic or primary measures, directly assessing the research substance through its rigor, aesthetic quality, the fit between theory and data, and its power to tackle unresolved questions.
3. Leveraging of integration. Integration is the critical assessment point for transdisciplinary research, aiming to balance and interweave perspectives to form a coherent whole and achieve effective synthesis. In the case of EEPHE, from the fields of electrical, mechanical, programming, etc., achieve effective synthesis. To monitor this, ex ante evaluation requires ensuring that the project has a unifying principle or set of questions to provide coherence, verifying the use of established integrative techniques (e.g., the Delphi method or general systems theory), and tracking the alignment of the organizational, methodological, and epistemological components.
4. Interactions of social and cognitive factors in collaboration. The development of EEPHE is fundamentally a 'social process of technical knowledge production' that requires the interaction of social and cognitive factors in collaboration. For success, it is crucial to calibrate separate disciplinary standards and manage tensions between specialities through compromise and negotiation. In this context, systematic communication between students who play roles as engineers, designers, and stakeholders is indispensable for building mutual knowledge and establishing integrative frameworks that unify the technical solution.

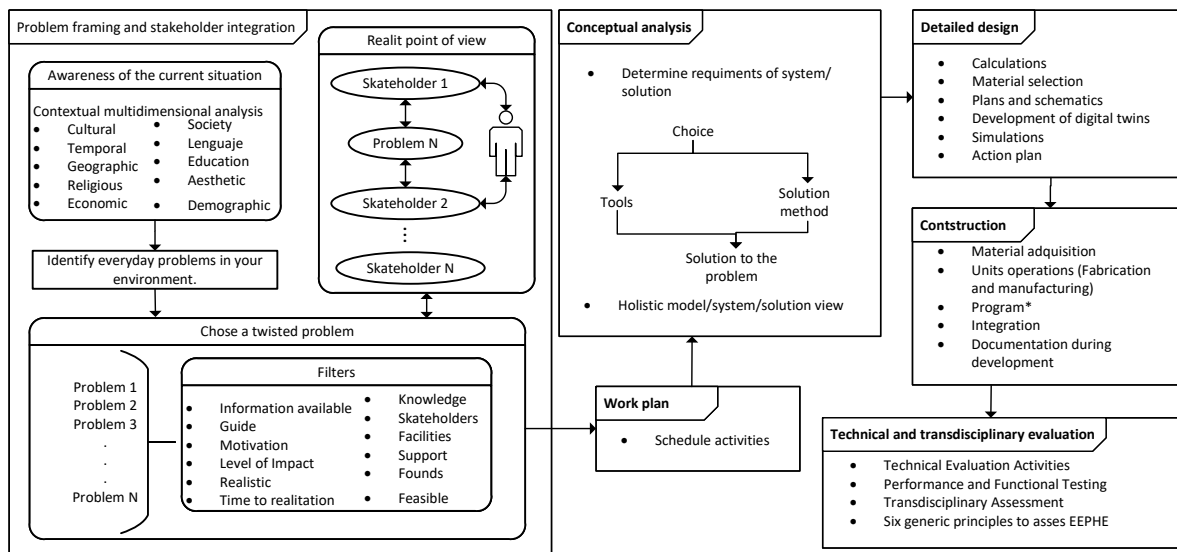
5. Management, leadership, and coaching. The role of AoE is to calibrate and manage standards and tensions across different disciplinary approaches within the student team. Should be carefully managed in balancing acts that require negotiation and compromise.
6. Iteration and feedback in a comprehensive and transparent system. Particularly in EEPHE, to ensure sustained collaboration, transparency, and common stakeholder participation. For effective assessment, indicators must have a non-linear feedback relationship with the project's progress. Crucially, transparency requires that the assessment criteria be known and, ideally, defined by both evaluators and participants from the very beginning of the project.

Most of the time, assessing the effectiveness and impact of TD is diffuse, delayed, and dispersed, especially in the long term. We do not consider it for assessment under the EEPHE, using a TD approach. However, the goal is to develop new knowledge from EEPHE.

The stage concludes with a review of the collaborative process, using team reports or reflective feedback. The goal is to document the strengths and weaknesses of the transdisciplinary methodology for managing complex engineering challenges, and to provide key findings for future project refinement and lessons learned.

## 4 Results and Discussions

Figure 5 synthetically represented the methodological EEPHE under a Transdisciplinary Approach, called ATLAS-IEME; due to the Spanish acronym for Electromechanical Engineering. This is visually simple; the six stages are clearly identifiable. The first stage is the main one and the hallmark of this methodology. It introduces transdisciplinary concepts, fosters Transdisciplinary Literacy, and guides the training of professionals with a holistic and systematic vision, aware of their surroundings and the tools at their disposal to address the technical aspects of the world's complex problems, taking into account the actors involved in these issues. Stage one isn't just an introduction, but a "Mental Shift" where students learn to identify the Hidden Third, the space where technical engrains, and social needs meet.



**Figure 5:** Development of University Electromechanical Engineering Projects under a Transdisciplinary Approach ATLAS-IEME.

While Rincón Pardo and Narváez Tovar (2024) successfully integrate subjects through mechanical design, the ATLAS-IEME methodology provides a critical advancement by anchoring the project's inception

in stakeholder dialogue. By moving beyond the internal university 'bubble,' our approach ensures that the 'Industrial Need' is balanced with 'Social Robustness,' addressing the 'Very Wicked' nature of problems that traditional interdisciplinary models often overlook.

The methodological proposal has the same application duration as that used by Rincón Pardo and Narváez Tovar. (2024). However, although "Appropriation of knowledge about machine design through the interdisciplinary integration of subjects by projects" focuses on mechanical design and mentions that all the resulting projects are related to beneficial technical and social problems, without stakeholder participation from the start, a project remains Interdisciplinary at best, but fails to be Transdisciplinary because it ignores the life-world context. Instead, the ATLAS-IEME proposal emphasizes social robustness through development with stakeholder participation.

An alternative approach to evaluating TD projects is that presented by Stokols et al. (2003), which establishes two levels of evaluation, micro and macro. The first level identifies three critical dimensions: background (personal, environmental, and organizational factors), processes involved (social, emotional, and intellectual), and outcomes (new concepts, methods, interventions, and training programmes). On the other hand, the macro level traces a path from basic activities (training and collaboration) to immediate markers (publications), intermediate markers (recognition and institutionalization), and long-term markers (health impacts and policy changes). Similarly, this approach uses a combination of qualitative and quantitative methods to capture the complexity of the process: interviews and surveys, meeting observations, content analysis, and financial analysis to determine how resources are used.

The creation of a project bank promoted by academics and industry is another way to encourage students who do not yet have clear ideas. A project bank isn't just a list; it is a boundary object that allows industry and university to speak the same language. At the same time, universities should consider a budget section to fund projects; even if the contribution is modest, excluding those sponsored by industry, this will encourage and guarantee students' commitment to starting, developing, and completing projects, as well as generating an ecosystem of innovation. Both student projects and academic-industrial projects have the same capacity for students to acquire specific and cross-cutting competences, and develop skills and qualities for student development (Aznar et al., 2015; Ledoux & Slaboch, 2025). A more participatory role is suggested for teachers and academics to enrich a project bank, which will subsequently be screened according to criteria established by an Academic Council.

## 5 Conclusion

A good engineer transforms their environment... for the better, considering its context and having a significantly positive social impact on those within it. It's necessary to include a transdisciplinary engineering course in the professional engineer's formation.

The implementation of the ATLAS-IEME method represents a disruptive evolution in the training of electromechanical engineers, shifting the focus from simply solving isolated technical problems to ethically addressing wicked problems with high social impact. The six proposed stages, from problem framing to transdisciplinary evaluation, offer a structured roadmap that balances technical rigour with social sensitivity. Beginning with a Multidimensional Context Analysis (cultural, economic, historical, etc.) is essential for students to understand that their design does not operate in a vacuum but in a complex, changing reality. This proposal converges the pragmatic vision of the Zurich school (co-creation with social actors) with Nicolescu's ontological vision (levels of reality and the third included). This integration allows technological development to be not only an exercise in functional optimisation, but also an ethical and responsible response that incorporates the vision of multiple stakeholders.

Furthermore, the integration of Digital Twins and Technology Readiness Levels (TRL) transcends traditional utility; these tools function as 'virtual mediators' that anticipate socio-economic and ethical repercussions within a simulated space of complexity. Ultimately, this approach redefines the roles within the classroom: the teacher emerges as an Advisor or Educator (AoE), facilitating a collective production of knowledge, while the student graduates not just with technical skills, but with a 'transdisciplinary attitude.'

They are prepared for a professional world where the convergence of realities is the only path to sustainable and meaningful innovation.

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