

How to Invent a Robot: Designing Innovation Environments for Framing and Solving Complex Problems

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ABSTRACT

Many limitations of engineering-driven innovation emerge before any final technology is built, often in the early conditions that shape how problems are understood, decisions are made, and collaboration unfolds. Drawing on a reflective, practice-based, and comparative methodology across research, education, industry, startups, and public innovation contexts, this article identifies recurring patterns in how innovation settings shape problem framing, collaboration, and decision-making. It then introduces How to Invent a Robot as a practice framework grounded in these observations and in sustained professional experience leading interdisciplinary teams and innovation processes. The framework brings together principles of interdisciplinary collaboration, multidimensional relevance, participation, learning, and enabling governance to support work under conditions of uncertainty and complexity. Particular attention is given to the growing role of artificial intelligence as an infrastructural component of such settings, where it may reproduce existing weaknesses or enhance coordination and collective intelligence depending on its design and governance. The article concludes that innovation outcomes are shaped by technological capability and by the quality of the conditions in which people think, decide, and create together.

1. Introduction

Contemporary debates on artificial intelligence and technological innovation are shaped by uncertainty. Public and professional discussions move between expectations of greater efficiency and concerns about loss of control, social disruption, and unintended consequences. At the same time, AI systems are becoming embedded in everyday work processes, influencing how information is generated, filtered, and acted upon. They increasingly shape perception, judgment, and decision-making within organizations and institutions.

Engineering innovation drives many of these developments and is often associated with objectivity, analytical rigor, and solution-oriented problem solving. These approaches

have delivered extraordinary progress across industries and remain indispensable for complex technical challenges. Yet they often treat problems as given and innovation as the search for the best solution under defined constraints. Design theory has long challenged this assumption. Simon (1996) described design as the transformation of existing situations into preferred ones, shifting attention from solution optimization toward problem framing and the choice of desirable futures.

Innovation processes are also shaped by social and organizational conditions such as institutional structures, available tools, and the environments in which collaboration takes place. Technologies, in turn, reshape routines, coordination, and interpretation rather than functioning as neutral instruments alone (Leonardi, 2011). Despite their shared relevance to contemporary challenges, engineering and the social sciences often remain insufficiently connected in both research and practice.

One example, drawn from the author's involvement, is an EU-funded robotics project intended to help older adults remain independent in their homes for longer. The project was highly ambitious and developed at a time when several key technologies were still emerging. As the work progressed, integration of the overall robotic system became the central priority. Delivering a functioning prototype was necessary for user tests and project milestones. Considerable effort, therefore, went into combining subsystems such as navigation and manipulation into a coherent whole. The project achieved meaningful technical progress, yet its original societal ambition was only partially realized. The case illustrates how technological maturity, integration demands, delivery pressure, and evaluation structures influence priorities, often without explicit intent.

More broadly, engineering-driven innovation is influenced by economic, organizational, and institutional conditions. Startups, corporate units, and publicly funded projects all operate under expectations of efficiency, scalability, and measurable impact. Siloed structures, hierarchical decision-making, and resource constraints further influence how problems are defined and addressed. Under such conditions, problem framing is rarely fully open-ended. It is often steered toward formulations that are actionable, fundable, and compatible with existing structures, translating complex and context-dependent challenges into simplified solution narratives.

This tension is especially significant in deep tech fields such as artificial intelligence and robotics, where technologies operate within complex social and organizational systems. Before solutions are developed, teams make choices about how the problem is

defined, whose perspectives are taken seriously, and how success will be judged. These early decisions shape the direction of development and the way technologies are later used and governed. Rittel and Webber (1973) described such challenges as situations in which goals are contested, conditions evolve, and interventions reshape the problem itself. Addressing them, therefore, requires perspectives that reach beyond technical feasibility alone.

Interdisciplinary collaboration, co-creation, and reflexive practice offer ways to broaden problem framing by bringing multiple forms of expertise and experience into interaction before premature convergence occurs. In practice, however, such collaboration is difficult to sustain. Differences in language, methods, epistemic assumptions, institutional incentives, and professional cultures often create friction rather than integration.

Educational research has developed pedagogical approaches that respond to these limitations. Constructionist and maker-oriented approaches emphasize learning through making and collaborative work on meaningful challenges (Blikstein, 2013). Project-based learning has been widely shown to connect technical knowledge with teamwork, creativity, and real-world problem solving while strengthening links between theory and practice (Lavado-Anguera et al., 2024). Yet engineering education often still prioritizes discipline-specific training and solution-oriented performance. These insights remain only partially embedded in mainstream curricula, where established structures often favor standardization, specialization, and short-term outputs. Recent comparative work suggests that interdisciplinary engineering education emerges through different combinations of curricular, organizational, and project-based structures shaped by institutional context (Xu, 2025). Embedding such approaches, therefore, often requires organizational redesign, leadership support, and coordination across existing boundaries (Lima et al., 2017). Opportunities to engage systematically with uncertainty, social context, and long-term consequences remain limited.

These educational debates point to a broader issue. Across classrooms, research projects, startups, public institutions, and corporate innovation settings, outcomes are shaped by the environments in which people work together. Participation structures, recognized forms of knowledge, support for experimentation, and evaluative criteria influence how problems are understood and which solutions become possible. This article, therefore, asks a central question: What kind of environments are we building for thinking, deciding, and creating together?

The insights developed in this article are relevant across multiple domains of innovation practice. They speak to practitioners engaged in technology development and interdisciplinary collaboration, to researchers examining the social and institutional dimensions of innovation, and to policymakers and institutional actors shaping the conditions under which such work takes place.

The article first outlines the perspective and context from which the observations are derived, including the interdisciplinary learning and innovation environments in which they emerged. It then identifies recurring patterns in how problem framing and problem solving unfold in practice and examines moments of intervention and their effects. Finally, it discusses how to better design innovation environments to support deep tech development in contexts where artificial intelligence and robotic systems increasingly interact with human decision-making and organizational structures.

2. How to Invent a Robot: an Experience-Based Practice Framework

2.1. Author's Background

The perspective developed in this article is grounded in more than two decades of work across research, education, and applied technology development in artificial intelligence, robotics, and interdisciplinary innovation. This includes experience in industrial engineering, product and project management, AI- and robotics-based system development, interdisciplinary research, higher education, and European and national innovation projects, including acquisition, coordination, and proposal evaluation. Work with startups, corporate units, and public funding bodies has further provided insight into how early-stage ideas are translated into concrete projects under conditions of uncertainty, time pressure, and resource constraints.

Across these contexts, a central focus has been the design and facilitation of environments in which collaboration, technological development, and learning unfold productively. This has involved aligning diverse perspectives, enabling cooperation across disciplinary boundaries, and building shared understanding between technical and non-technical actors. Because this work spans industry, research, higher education,

startup ecosystems, and funding environments, it enables a comparative view of how innovation processes develop under different institutional logics, constraints, and expectations.

2.2. Method

The methodological approach of this article is reflective, practice-based, and comparative. It generates knowledge through active involvement in real innovation processes across multiple settings. These are treated as sites of inquiry in which innovation unfolds under practical constraints such as uncertainty, time pressure, or competing interests.

The analysis focuses on recurring dynamics: how problems are framed, how decisions are made, how collaboration develops across disciplinary boundaries, and how structures shape participation and direction. Understanding emerges through the interplay of observation, action, and intervention. Assumptions are surfaced, methods are introduced or adapted, and their effects become visible while processes are still unfolding. Reflection is therefore embedded in practice rather than postponed until the end.

A central element of the approach is comparative interpretation across contexts combined with theory from multiple disciplines. Concepts from engineering, management, and organization studies, design, education, the social sciences, and the humanities help explain patterns that recur across otherwise different environments. At the same time, theoretical knowledge is translated back into methods, tools, and interventions for practice. The process is iterative: practice generates observations, theory supports interpretation, interpretation informs action, and action generates further learning.

2.3. How to Invent a Robot as a Practice Framework

How to Invent a Robot is the experience-based practice framework through which innovation environments are designed for framing and solving complex problems under conditions of uncertainty and complexity. It emerged through repeated work across research, industry, education, and technology development, where interdisciplinary teams had to move from ambiguous challenges toward actionable outcomes. The framework

combines elements of constructionist learning, human-centered design, and reflective facilitation, while also drawing on routines from industrial practice such as project management, agile coaching, and human resource development.

One application of the framework is a university learning environment in which students from engineering, architecture, and science work in interdisciplinary teams on real-world challenges linked to the Sustainable Development Goals (Jäggle & Lammer, 2026). In this setting, the broader framework is translated into higher education through collaborative problem framing, user-oriented research, concept development, prototyping, iterative pitching, and guided reflection.

The learning environment integrates technical competence, creativity, teamwork, and societal context through project-based work on open-ended challenges. Students develop technological literacy alongside scientific, entrepreneurial, and conceptual thinking. They investigate evidence, question assumptions, identify opportunities, work with uncertainty, negotiate different perspectives, give and receive feedback, reflect on their process, and explain why their proposed direction matters.

Across multiple iterations, the course also serves as a structured experimentation space in which the framework is enacted, observed, and refined. Student reflections, discussions, and project artefacts provide additional insight into how participants experience collaboration, uncertainty, agency, and responsible technology development.

3. Recurring Patterns and Moments of Intervention

Building on the observations and comparative methodology outlined in Chapter 2, this chapter identifies recurring patterns in how problems are framed and addressed across engineering-driven innovation contexts. Despite differences in setting, similar dynamics appear repeatedly: early convergence around solvable problems, the influence of tools, the challenges of interdisciplinary collaboration, the structuring effects of organizations, and the limited role of reflection during ongoing work. Each section combines observations from practice with moments of intervention that revealed these dynamics or opened alternative pathways for action.

3.1. Early Convergence on Solvable Problems

A recurring pattern in engineering-driven innovation is early convergence around solvable problems before uncertainty has been adequately explored. When challenges are still open, unclear, or difficult to define, teams are often drawn toward formulations that are easier to understand and to solve. Complex situations are narrowed into manageable tasks, ambiguous questions become technical requirements, and broad societal issues are reframed to fit familiar tools and routines. This creates momentum: work can be assigned, prototypes developed, and progress demonstrated. At the same time, important parts of the original challenge may disappear before they have been properly examined.

One example is a proposal for an AI-based startup founder matchmaker. In early-stage ventures, investors often place as much weight on the founding team as on the idea itself. Products change, markets shift, and business models evolve, but dysfunctional teams can destroy even promising opportunities. The starting concern is therefore real: many startups struggle because founders face unclear roles, communication breakdowns, loss of trust, or unresolved conflict under pressure. The proposed solution suggests assessing potential founders through personality tests such as the Big Five or Myers-Briggs, translating selected traits into data, and using an algorithm to predict promising team combinations. A difficult and uncertain question of human collaboration is thereby converted into a structured technical challenge.

The limitation lies in the assumptions behind the model. Startup teamwork develops through dialogue, changing responsibilities, shared setbacks, negotiation, and the ability to work through disagreement over time. Profiles may offer useful signals, but they do not determine how people grow together under real conditions. More revealing is how tools designed for assessment are repurposed as instruments of prediction. If the team had remained longer in the problem space and given equal weight to both psychological and engineering perspectives, they might have developed a solution that supported stronger team formation: helping founders compare working styles, identify likely friction points, and prepare consciously for collaboration. In that form, technology would strengthen human judgment rather than replace it.

A similar pattern appears in the interdisciplinary learning environment, *How to Invent a Robot*, where student teams work on broad challenges linked to the Sustainable Development Goals. Faced with open societal problems, many teams seek immediate clarity by selecting familiar and publicly validated topics. Ocean-related projects become

projects about plastic waste. Consumption-related projects become projects about fast fashion. These topics are legitimate, but they are also easy to explain and already framed as recognizable problem narratives. The topic itself creates a sense of progress before substantial discovery has taken place. Teams begin generating solutions without yet understanding whose problem they are addressing, in which context, or why current practices persist.

Two coached student teams illustrate how the same intervention produces different outcomes under different conditions. One team, working on SDG 10 (Reduced Inequalities), consisted of two environmental chemists and two computer engineers. At the outset, the challenge remained abstract, and the group wanted clearer direction. The intervention was to stay longer in the problem space, investigate realities connected to their own fields, and postpone premature solution decisions. This phase was experienced as difficult and generated frustration, uncertainty, and tension. Different working orientations became visible: the exploratory phase appeared easier for the environmental chemists, while the computer engineers showed a stronger preference for earlier movement toward solutions. Through continued research, discussion, and reframing, the team identified a concrete issue not visible at the outset: long-term pesticide exposure among winemakers and the fact that Parkinson's disease is not recognized as an occupational disease for winemakers in Austria. Once the problem was clarified, the same engineers contributed strongly to developing an effective solution space.

Another team worked on SDG 16, focused on peace, justice, and strong institutions. The intervention was similar: examine the underlying challenge first, question assumptions, and avoid rushing into a predefined concept. The outcome differed. Composed of electrical and computer engineers, the team quickly centered its work on a security drone supported by detection technologies. Feedback was taken seriously and implemented with discipline, but mainly at the level of technical features or storytelling. The central concept remained unchanged. Questions of trust, prevention, legitimacy, participation, or the social causes of insecurity stayed largely outside the frame. Reflection improved the existing solution, but the problem definition remained closed. Together, these projects show that methods alone do not determine outcomes. What matters is whether teams are willing and able to remain in uncertainty long enough for reframing to occur.

A related example comes from a PhD student trained in mechatronics engineering who had participated in the same interdisciplinary learning environment. There, he learned to

remain in the problem space, investigate user realities, and iteratively reframe challenges before committing to technical solutions. He later applied this approach to precision agriculture, a field often dominated by visions of autonomous machines and highly automated farm operations. His initial research focused on interviews with farmers and on understanding everyday agricultural realities before proposing a technical intervention.

This change in sequence proved consequential. The resulting work highlighted a gap between the priorities driving robotics research in precision agriculture and the actual needs expressed by farmers. Many challenges related less to futuristic high-tech solutions than to practical usability, integration into existing workflows, affordability, reliability, and relevance under field conditions. Building on these insights, he later developed an AI-based computer vision approach that uses an RGB camera to detect soil pH values, enabling low-cost implementation through widely available devices such as smartphones. The case shows that advanced technology becomes most useful after the underlying problem has first been understood clearly.

Across these cases, early convergence is rarely the result of poor thinking or lack of motivation. It reflects environments that reward visible progress and rapid answers more consistently than exploration. Different outcomes emerge when uncertainty is treated as part of the work, when teams investigate lived realities, and when reframing remains possible. Under these conditions, more relevant challenges become visible, creating the basis for more meaningful and effective solutions.

3.2. Tools and Systems Shape What Is Thinkable

A second recurring pattern is that technical tools and systems shape what becomes relevant and plausible during innovation processes. Every platform, interface, or model carries assumptions about which inputs matter and what kinds of outputs are expected. Because tools are often treated as neutral support, these assumptions often stay invisible while still influencing both perception and thinking.

One example is a hybrid meeting room equipped with an AI-supported camera system. When no one is speaking, the system shows the full room. When a participant begins to speak, it automatically focuses on the active speaker. During one meeting, female voices were filtered as background noise, so contributions were not heard. The predominantly

male group did not immediately recognize the failure and wanted to continue because of time pressure. A female AI expert insisted that the issue required attention. After this intervention, the IT staff member changed the group profile. Female voices were then transmitted more reliably, yet women were still not centered on screen when speaking, while male speakers were highlighted correctly. What appeared to be seamless technical support became a visible source of asymmetry within the meeting itself. The issue is technically a classification error, yet its significance extends beyond the technical level. The system shaped participation by determining whose contribution entered the shared auditory and visual space, and whose faded into the background. Those affected first had to notice the pattern, then accept the social risk of raising it, and insist that the problem was real.

A related example appears in a dementia care project using a humanoid social robot. The robot was engaging, approachable, and effective in attracting attention. It motivated participation and helped structure exercises in ways that felt more playful and relational than conventional formats. Its social presence created forms of engagement difficult to achieve with standard devices alone. At the same time, the platform also defined the limits of what could be developed around it. Many functions were predefined, the architecture was relatively closed, and new ideas had to fit within existing technical boundaries. Innovation was therefore shaped both by the needs of the care context and by what the robot had already been designed to do. The case illustrates both sides of the pattern: technologies open possibilities through their specific qualities while narrowing imagination through built-in constraints.

The same dynamic appears in an educational outreach setting where children were asked to invent future robots. The process began with two simple questions: for whom is the robot, and what should it do? Before developing concepts, participants were introduced to basic robot components and shown different design possibilities, including anthropomorphic, zoomorphic, cartoon-like, and machine-like forms. Many quickly moved toward a familiar image. Most designed humanoid robots with heads, faces, arms, voices, and personalities, while zoomorphic forms were the second most common choice. Even in a creative setting that began with user and task considerations, existing cultural narratives strongly shaped what seemed like a robot in the first place. The influence of systems, therefore, begins long before formal decision-making. It is present in the images, categories, and expectations people bring into design situations.

The history of domestic robotics offers a revealing counterexample. For many years, popular imagination pictured household robots in humanoid form: machines shaped like people using tools and appliances designed for human bodies. The most successful domestic robot followed a different logic. Instead of imitating a human using a vacuum cleaner, the early iRobot platform redefined the task itself and created a machine designed specifically for floor cleaning. Its round form, autonomous movement, and narrow functional focus departed from dominant cultural images of household robotics. The concept emerged from sustained research at MIT and required years of market learning and refinement before large-scale adoption followed. What is striking is how stable the underlying design remained. Later generations introduced improvements such as docking stations, wet cleaning functions, and alternative geometries, while the core concept changed little. Once a technological form aligns task, environment, and user value, it shapes expectations for an entire field.

The influence of tools becomes especially visible in the interdisciplinary learning environment, where student teamwork is documented and compared across the period before generative AI and the present. Many teams use generative AI for brainstorming, structuring concepts, drafting texts, producing images and pitch decks, naming ideas, market research, and generating first solution directions. The immediate effects are speed, reduced hesitation, and greater confidence. Blank pages disappear faster, options emerge sooner, and teams move more quickly into action.

At the same time, another pattern emerges. AI outputs often reproduce dominant patterns already present in the models: familiar solution logics, plausible generalities, standardized language, and ideas that sound convincing before critical examination. Some teams, therefore, converge faster, but also more narrowly. This becomes clear when students struggle not with answers, but with questions, as reflected in one student's outburst: "I don't even know what question to ask, as you do!" A smaller number of teams avoid AI entirely. Earlier reluctance was often based on skepticism; more recent resistance is frequently linked to frustration with generic or unreliable outputs. In practice, however, these teams often progress more slowly than peers who use AI productively.

The challenge in this context is increasingly that students must learn to frame problems, identify tensions, and ask useful questions. They need to use AI to strengthen collective intelligence rather than outsource thinking. When students question outputs, compare alternatives, revise prompts, and reintroduce their own observations from users or

context, the tools become productive support. When outputs are accepted too easily, the system begins to frame the project itself.

Across these observations, tools and systems emerge as active components of innovation environments. They shape what is noticed, how situations are interpreted, which options gain legitimacy, and how quickly certain directions become established. Their influence often remains implicit because it is embedded in ordinary workflows and routines. The recurring interventions are therefore often small but important: making hidden assumptions visible, questioning outputs that appear authoritative, comparing alternatives, returning attention to user realities, or asking whether the tool is shaping the problem itself.

3.3. Interdisciplinary Friction Without Translation

A third recurring pattern is that diversity expands the range of available knowledge, perspectives, and methods, but only if integrated well. Teams consist of highly capable people and still struggle to create shared progress. Different disciplines often approach the same challenge with different languages, assumptions, time horizons, and standards of what counts as a good solution. Without translation, these differences turn into friction, parallel work, or a hidden hierarchy.

A positive counterexample appears in a European research project that aimed to attract more young people to STEM fields through educational robotics. The project brought together partners with different institutional backgrounds, expertise, and priorities. Collaboration was designed deliberately from the outset. A matrix structure assigned formal responsibility for each work package to one partner, while all other partners contributed substantially across the project instead of remaining peripheral participants. Shared ownership was built into the architecture of the collaboration itself.

Communication structures were equally important. An extended kick-off phase created time to align expectations towards a common vision of what the project should achieve, clarify roles, and understand how the different organizations work. Regular meetings sustained coordination and made emerging tensions discussable before they hardened into conflict. Through ongoing dialogue, the consortium developed a functioning collaborative culture rather than relying only on contractual structures. The project was later recognized by reviewers as having exceeded expectations. The case shows that

interdisciplinary success depends on environments that support translation, shared responsibility, and continuous communication.

Across many other settings, team composition also proves decisive. The question is rarely whether a team is capable or motivated. More often, the question is whether different forms of thinking are present and whether the environment enables these differences to interact productively.

This dynamic becomes especially visible in one student project of four architecture students within the interdisciplinary learning environment. From a conventional perspective, the team appears unbalanced for a technology-oriented innovation challenge. In practice, it becomes a major strength. The students identify the spread of an invasive Argentinian ant species in southern Europe as a serious but little-discussed issue. Rather than rushing toward a single prototype, they develop a broader systems-oriented roadmap. The first stage involves the development of a robotic solution by a technical university for collecting ants together with a partner university that studies the collected ant species in a subsequent project. Later stages also consider humane extermination and the possible reuse of chitin in future value chains.

What makes the project remarkable is the kind of thinking behind it. The team is not constrained by immediate implementation logic. It moves confidently between ecology, design, long-term scenarios, scientific collaboration, and technical possibility. Its conceptual freedom expands the problem space before narrowing it. This wider problem space creates additional entry points for collaboration, allowing different actors, forms of expertise, and future partners to contribute to the emerging solution space. New synergies become visible because the challenge is not reduced too early to a single technical pathway. In this case, the absence of narrow disciplinary feasibility thinking becomes an advantage.

A different dynamic appears in another project with three architecture students and one engineering student. The team develops a highly imaginative concept and generates strong momentum in the early phases. The architecture students drive exploration, storytelling, and bold scenario thinking, while technical implementation rests largely with a single engineer. This asymmetry becomes increasingly relevant once the project moves from concept generation toward realization. Questions of system design and translation between vision and implementation become harder to absorb through one disciplinary perspective alone. The case shows that creativity and technical realization

require sufficient diversity across perspectives with active mediation between exploratory and execution-oriented forms of work.

Another revealing moment emerges in a feedback discussion with a mathematically trained participant. She asks the coach directly to explain why the proposed concept does not resonate. The coach responds that such a reaction does not require immediate rational justification to be valuable. She is initially perplexed and later understands the point. The intervention lies in slowing the demand for premature explanation and creating space for tacit judgment, intuition, and implicit criteria to become discussable. Interdisciplinary collaboration often deepens when different ways of knowing are taken seriously alongside explicit arguments.

Student reflections across multiple iterations in the learning environment describe the same dynamics from the inside. Many participants experience interdisciplinary teamwork as both demanding and valuable. Several report that team members initially talk past one another, approach tasks with different priorities, or disagree about what counts as progress. Others describe learning, often for the first time, how to communicate with people who think and work differently from themselves.

These reflections show that friction in interdisciplinary teams often marks the effort of different knowledge systems trying to connect. With dialogue, feedback, and shared tasks, initial tension frequently develops into mutual respect and stronger collaboration. Without such support, differences more easily harden into misunderstanding or parallel work. The recurring interventions are therefore often practical and relational: structuring collaboration deliberately, creating shared tasks, clarifying expectations, surfacing hidden criteria, and facilitating dialogue when tensions emerge.

3.4. Organizational and Social Dynamics Shape Direction

A fourth recurring pattern is that innovation trajectories are shaped early and decisively by the social and organizational environments in which they unfold. Hierarchies, routines, incentive structures, professional identities, funding logics, and informal power relations influence which questions are taken seriously, which concerns are ignored, and which forms of progress are rewarded. These dynamics often remain less visible than the technology itself, while strongly directing outcomes.

A previously introduced European research consortium illustrates this pattern at the macro level. The project was built around the mission of supporting older adults in remaining independent in their homes for longer. The participating partners brought substantial expertise. Everyday collaboration was nevertheless shaped strongly by university hierarchies, disciplinary silos, and limited experience with the integrative project management required for highly complex socio-technical systems. These conditions influence how collaboration unfolds. Responsibilities are distributed across specialized domains, while interfaces between domains receive less systematic attention. Coordination across institutions is demanding, and not all partners are equally prepared for the managerial effort such a consortium requires. Some forms of expert culture complicate dialogue. Strong disciplinary confidence, particularly in highly specialized engineering areas, narrows openness toward perspectives from other fields. When technical certainty combines with hierarchical structures, broader viewpoints are often dismissed before serious examination.

The pattern also appears in a very different organizational setting at the executive level. In this case, the barrier is the internal logic of managerial action. A senior leader develops a clear strategic direction and searches for concrete actions to implement it. Stakeholders are identified, objectives are formulated, and the discussion focuses on which initiatives should be launched. The process appears advanced because the solution space is already populated with possible measures. An important layer remains underdeveloped: The needs, motivations, constraints, and everyday pain points of the relevant actors have not been explored in depth. The strategic challenge is translated directly into action planning without sufficient work in the problem space. Proposed measures risk addressing assumptions about stakeholders rather than their actual realities. The intervention is to slow the move toward execution and return to inquiry. The discussion shifts toward how different groups experience the current situation, where friction exists, and what makes change meaningful from their perspective. This episode highlights how organizational momentum often privileges visible action and compresses space for deeper understanding.

The same dynamics are visible at the micro level of teams. In team-building settings, groups are encouraged to reflect on how ideas enter the discussion. More extroverted participants often generate and defend proposals quickly, shaping direction early. More introverted participants frequently enter later with critique, refinement, or reservations. Their responses are sometimes interpreted as negativity or resistance. Facilitation often reveals that the issue lies in interaction design rather than personality alone. Some

participants receive immediate space to think aloud, while others need time and space on their own to develop and formulate contributions. When discussions move too quickly, speed becomes mistaken for competence and hesitation for resistance. Once this pattern becomes visible, the quality of collaboration changes. The intervention is simple and effective: vary formats of participation, create moments for individual reflection before group debate, and structure turn-taking so that speed does not automatically become influence. The case illustrates how even small interaction routines shape whose contributions guide collective decisions.

Across these cases, organizational and social dynamics shape innovation far earlier and more deeply than formal plans or technical specifications suggest. They distribute attention, legitimacy, and participation within collective work. They influence how problems are defined, which perspectives enter consideration, and whose contributions carry weight in decisions. Much of this influence remains embedded in ordinary structures and routines, which makes it easy to overlook while still strongly affecting outcomes.

The recurring interventions in such settings are both structural and interpersonal. They include redesigning coordination across boundaries, strengthening integrative leadership and project management capacity, creating shared ownership, surfacing cross-cutting issues early, and establishing dialogue between specialized expertise and broader system perspectives. They also involve distributing participation more deliberately and examining the hidden assumptions built into everyday routines and decision processes.

3.5. Reflection Is Structurally Absent

A fifth recurring pattern is that reflection is widely valued in principle but rarely protected in practice. Most innovation environments reward visible movement: execution, delivery, milestones, prototypes, reporting, and measurable progress. Time spent questioning assumptions, reconsidering direction, or pausing to examine whether the right problem is being solved is harder to justify. Reflection, therefore, becomes something postponed to the end of a project, delegated to formal review or lessons learned sessions, or omitted entirely.

The absence of reflective capacity becomes especially visible in conversations with senior leaders. In several executive settings, the decisive challenge is not a lack of

intelligence, data, or strategic ambition, but the lack of protected spaces in which fundamental questions are explored outside hierarchy, performance pressure, and immediate deadlines. Status meetings focus on updates, targets, and next steps. Operational pressure favors immediate decisions. Under these conditions, deeper questions about assumptions or direction remain secondary, even when leaders recognize their importance.

A related perspective emerges in conversation with a senior executive responsible for complex projects under strong delivery pressure. He recognizes the value of pauses for reflection and reframing, yet questions how such moments could exist within environments defined by deadlines, fixed directions, budgets, and contractual commitments. From within the logic of the project system, stopping to reconsider appears unrealistic. This line of thought is revealing because it expresses a widespread managerial assumption: reflection belongs outside execution, while projects are spaces for delivery alone. This logic shapes many conventional project environments, where learning is deferred to post-project reviews and adaptation is treated as deviation from plan rather than part of responsible steering.

The same pattern appears in publicly funded innovation contexts. Once proposals are approved, projects are typically steered through predefined work packages, milestones, deliverables, budgets, and key performance indicators. These structures create accountability and are often necessary for coordination across multiple actors. However, this becomes problematic when implementation generates new insights. Teams often learn about differing user needs during the project, that technical pathways are less promising than expected, or recognize more relevant opportunities during the project itself. Substantial changes remain difficult to pursue because reporting obligations and evaluation criteria stay tied to the approved plan. Deviation requires justification, administrative effort, or threatens formal success. Under such conditions, a project satisfies contractual expectations while moving further away from the most meaningful direction. Learning is produced inside the project, but the surrounding structure limits how far that learning reshapes the project itself. Success risks becoming compliance with the plan rather than responsiveness to emerging reality.

A different orientation appears in the previously introduced doctoral project that develops an AI-based computer vision system for pH detection with a standard RGB camera. After the technical breakthrough, the next logical step is the creation of a startup. Work therefore shifts toward identifying viable use cases while, in parallel,

shaping the remaining academic research agenda. Rather than following a linear path from invention to commercialization, technical development, business exploration, and scientific inquiry interact continuously. Reflection is built into the structure of the process itself because strategic decisions remain open to revision as learning emerges. After extensive market research, stakeholder conversations, and a submitted funding proposal, an important constraint is revealed: the strongest business opportunities depend on additional technological solutions that do not yet exist. Immediate scaling, therefore, gives way to continued exploration. New technical questions are pursued alongside the original work, while commercial assumptions are revised in light of what has been learned. The case illustrates a different temporal logic of innovation. Progress does not always mean rapid execution toward a fixed target. In some contexts, responsible progress means allowing insight to reshape ambition, keeping multiple pathways alive, and accepting that meaningful development proceeds through iterative maturation rather than accelerated rollout.

The same temporal logic becomes visible in student reflections across multiple iterations of the learning environment. Many teams initially experience repeated reflection, user feedback, and iteration as obstacles to progress. They want to move quickly toward concepts, prototypes, and visible results. Returning to earlier assumptions, revising ideas, or questioning an already chosen direction is often described as frustrating while the project is underway. In later reflections, however, many students evaluate these moments differently. Iteration is described as essential for improving outcomes, user feedback is recognized as highly valuable, and earlier pauses for reconsideration are understood as decisive turning points in the project. Several students report that they first perceived reflection as slowing progress and only later recognized that it had prevented them from investing effort in weaker directions.

These accounts show that the value of reflection is often clearest in retrospect. During action, it competes with the immediate satisfaction of movement. After action, it is more easily recognized as a condition for better judgment and more meaningful innovation outcomes. The recurring interventions, therefore, concern the design of reflection time within ongoing work: creating protected moments for inquiry, integrating feedback before paths harden, allowing new learning to reshape decisions, and recognizing iteration as progress rather than detour.

Taken together, the five recurring patterns show that innovation outcomes are shaped by the environments in which people define problems, use tools, collaborate across

differences, navigate organizational structures, and make space for reflection. The central question is therefore how to design better conditions for thinking, deciding, and creating together, so that technologies serve economic and societal expectations.

4. Discussion

The observations across different innovation contexts show that many limitations of engineering innovation emerge long before any final technology is built. Many difficulties that later appear as technical failure, weak adoption, public resistance, or limited societal relevance arise earlier: when problems are framed too narrowly, when relevant forms of knowledge are excluded, when disciplines compete for dominance instead of contributing complementary insight, or when organizational routines reward execution over understanding.

The *How to Invent a Robot* practice framework addresses these challenges with principles and practices for shaping innovation environments in which problem framing, collaboration, and decision-making remain open to revision throughout the process. It combines innovation and management practices with theories and methods from engineering, science, and the humanities. Its elements operate as interacting components of a continuous learning process in which action generates insight and insight reshapes action.

Three guiding principles form the foundation of the framework. First, interdisciplinary collaboration requires active facilitation, translation, and shared working structures. Second, innovation requires alignment between technical feasibility, economic viability, human needs, and long-term societal responsibility. Third, participation and agency require real influence over decisions, shared responsibility, and opportunities for meaningful contribution. Realizing these principles depends on leadership and governance that embed them in everyday practice under conditions of time pressure, uncertainty, and conflict.

This becomes especially consequential with the growing integration of artificial intelligence into organizational and institutional workflows. Suchman (2007) emphasizes that technological systems acquire their practical meaning and effects through situated use. Applied to AI, this suggests that outcomes are not determined by technical capability alone, but by the organizational environments in which systems are

implemented and governed. As AI becomes part of the infrastructure, organizational routines, incentives, and governance arrangements increasingly shape whether it contributes to cooperation and learning or reproduces existing dysfunctions.

4.1. Facilitating and Negotiating Interdisciplinary Collaboration

Interdisciplinary collaboration is widely associated with innovation because complex challenges rarely fit within a single field of expertise. Technical specialists, designers, scientists, managers, and other actors often recognize different aspects of the same situation, apply different standards of evidence, and define success in different ways. This diversity expands the range of available interpretations and enlarges the space of possible solutions.

The difficulty lies in turning diversity into shared progress. Different disciplines often use the same words differently, prioritize different constraints, and follow different rhythms of work and decision-making. Misunderstanding, hidden assumptions, and competing definitions of progress easily slow collaboration or fragment teams into parallel tracks. Disagreement forms a normal part of such work. Its value depends on whether it leads to clearer understanding and better decisions.

The *How to Invent a Robot* practice framework responds to this challenge by establishing shared goals, visible roles, structured milestones, facilitated dialogue, and common artefacts that anchor discussion in concrete work. It also embeds routines for inquiry, feedback, iterative decisions, and revision so that learning remains part of execution. Constructionist learning, human-centered design, iterative development, project management, and reflective facilitation operate as connected elements within one collaborative process. In this way, cooperation becomes a deliberate organizational capability which develops through several enabling conditions.

A first condition is psychological safety and a developmental mindset. Participants need space to ask naïve questions, admit uncertainty, test unfinished ideas, challenge assumptions, and revise their views without loss of dignity or status. Fear of embarrassment or judgment reduces the knowledge available to the group, weakens experimentation, and narrows collective intelligence. In the interdisciplinary learning environment, students are explicitly told that the environment is a safe space for

exploration. They are expected to make mistakes, ask for help, use available tools, receive feedback, and try again. Instead of waiting for perfect instructions, they learn to act under uncertainty, persist through setbacks, and develop confidence through repeated cycles of experimentation, feedback, and progress.

A second condition is shared external work through tangible artefacts. Teams or consortia develop sketches, mock-ups, prototypes, user journeys, or scenarios that create common reference points for discussion. Tangible making improves collaboration because assumptions become visible. A particularly important artefact in the framework is the pitch deck. Students begin pitching ideas in the first unit and deliver a first deck by the third unit. They then refine it repeatedly after feedback. This process often reveals gaps in logic, unclear value propositions, weak user understanding, and missing connections between concept and execution.

A third condition is the combination of openness and structure. Effective interdisciplinary environments require freedom to explore unconventional ideas together with enough scaffolding to coordinate action and maintain momentum. Creativity and structure operate as complementary conditions of productive collaboration. Openness concerns both space and mindset: participants need room to test unconventional directions and an attitude of curiosity toward unfamiliar perspectives, tools, and challenges. The learning environment cultivates this through substantial freedom in topic choice, problem framing, and solution direction. Structure provides the counterbalance through clear phases, milestones, deliverables, and time-bounded decision points that prevent stagnation and translate ideas into action.

A fourth condition is orientation beyond internal team perspectives. Interdisciplinary teams need an anchor outside themselves where ideas are confronted with realities that do not originate inside the group or from formal authority alone. External feedback often carries particular value because it is experienced as evidence from practice rather than as instruction from hierarchy. An interdisciplinary engineering outreach team developed an interactive wall installation for visitors of the faculty to experience electrical engineering. The team had already built a relatively advanced prototype and continued refining its own ideas, ignoring feedback about having empathy with users or seeing the wall from "the eye of" the stakeholders. Only when teenagers were invited into the process, blunt reactions such as finding the wall boring immediately challenged internal assumptions and redirected further development. The team initially reacted with

surprise and embarrassment, yet the psychologically safe environment helped them absorb the feedback, learn from it, and use it constructively.

A fifth condition is structured reflection and constructive responses to error. Innovation under uncertainty includes weak assumptions, technical dead ends, surprising user reactions, and changing requirements. Teams learn faster when such moments are treated as information for adaptation instead of reasons for blame or defensiveness. This requires a growth mindset in which setbacks are understood as part of development rather than as fixed judgments of ability or failure. Reflection, therefore, concerns the evolving solution as well as communication patterns and obstacles in collaboration. Several student teams initially felt frustrated by critical feedback. However, after revising their ideas, many of these teams delivered substantially stronger concepts in later iterations and developed confidence in their abilities through the experience of learning.

Artificial intelligence has the potential to strengthen these conditions when used as a collaborative resource. A low-risk space for early questions, unfinished ideas, and experimentation supports exploration before public discussion. Rapid creation of shared artefacts such as visualizations, concepts, scenarios, and pitch materials makes collaboration more concrete. Used as a sparring partner that challenges assumptions, AI widens perspectives. Its value depends on whether these contributions strengthen human judgment, shared learning, and collective progress rather than displacing responsibility.

Taken together, these conditions suggest that effective interdisciplinary collaboration depends on environments that combine psychological safety, shared artefacts, openness with structure and mindset, orientation beyond internal assumptions, and continuous reflection with learning. Under these conditions, diversity becomes a productive resource rather than a source of fragmentation. Once collaboration is in place, the next question is whether the innovation addresses meaningful problems and remains relevant in technical, economic, and societal terms.

4.2. Aligning Innovation with Technical, Economic, and Societal Relevance

Engineering innovation creates value when technical capability, economic viability, and societal responsibility are held together throughout development. Strong engineering

performance remains essential, yet projects often lose relevance when optimization focuses on laboratory performance while everyday use conditions remain unexplored or when gains in one area create hidden costs elsewhere in the wider system.

The *How to Invent a Robot* framework builds on the established human-centered design perspective of technical feasibility, human desirability, and business viability, and extends it through a fourth dimension: societal and sustainability relevance. Innovation, therefore, involves four interdependent questions: what is technically possible, what people need, what remains economically viable, and what serves society responsibly over time.

Aligning technical, economic, and societal relevance is demanding because these dimensions often pull in different directions. Short-term priorities may conflict with long-term resilience, private incentives may not fully align with public value, and stakeholders frequently differ in how relevance is defined. Ethical principles or sustainability metrics often remain outside everyday project decisions as reporting tools or late-stage assessments. The framework addresses these challenges by integrating questions of relevance into ongoing project decisions rather than treating them as external assessments at the end of the process. Shared vision, adaptive roadmapping, continuous inquiry, and iterative decisions informed by practice-based evidence help teams balance technical, economic, and societal considerations as the work evolves. This form of multidimensional innovation depends on several enabling conditions.

A first condition is orientation toward real and meaningful problems. Strong projects begin with an issue that deserves attention, the people affected by it, and a clear reason why the challenge matters. Shared purpose strengthens motivation, persistence, and ownership because participants understand the significance of their work beyond task completion. In the student projects, engagement often increased substantially when teams connected abstract SDGs to concrete realities such as pesticide exposure among winemakers or ecological damage linked to invasive species.

A second condition is the continuous alignment of technical possibilities with real contexts of use. Innovation rarely emerges from technical development or user demand alone. It develops through ongoing exchange in which technical capabilities and user pain points inform one another. In precision agriculture, some efforts focus on technical capabilities such as mobile robotic platforms for uneven terrain. Other projects, such as the AI project on soil pH values, began from user needs and practical decision problems

in the field. Stronger innovation emerges when projects combine these perspectives so that technological opportunities and real-world applications shape one another throughout development.

A third condition is economic viability connected to genuine value creation. Sustainable innovation requires financial resources for development, early revenue or investment to support progress, and the capacity to create value over time for the organizations and users involved. Economic considerations are therefore essential, but they need to remain connected to broader goals of long-term usefulness and sustainability. A useful example comes from a student project that initially used robot vision and AI to detect invasive insects in trees during the larval stage. After pitching the concept, an exchange with a potential customer helped clarify practical applications, field requirements, and market demand. The idea subsequently evolved toward a bottom-up technology development pathway focused on drone-enhancing capabilities. This expanded the original vision by opening additional use cases, increasing commercial scalability, and creating broader pathways toward sustainable innovation. A business plan was developed, investor interest emerged, and financing efforts continued. Economic viability in this case developed through iterative refinement, external engagement, and the gradual translation of a technical idea into a commercially credible opportunity linked to a wider sustainability-oriented mission.

A fourth condition is societal and sustainability responsibility embedded in development itself. An innovation may retain or expand a sustainability-oriented mission while the underlying development process still requires deliberate attention to sustainability. The ways technologies are designed, resourced, manufactured, governed, and scaled shape future risks and opportunities. Some environmental and social effects remain unknown during development, making sustainability a continuing process of inquiry, evaluation, and adjustment. Relevance includes ecological effects, fairness, resilience, inclusive access, trustworthy institutions, and the capacity of systems to remain beneficial under changing conditions.

Empirical findings from the interdisciplinary teaching environment similarly showed that broad labels such as the SDGs rarely produced sustainable design thinking on their own. Many students engaged with sustainability at a surface level and treated the assigned goal mainly as a topic selection device rather than as a deeper orientation for decision-making. This finding indicates a missing element in the current framework. Explicit practices that connect sustainability to systems thinking, long-term consequences, ethical

trade-offs, and everyday design choices need to be integrated more directly into future versions of the framework (Jäggle & Lammer, 2026).

A fifth condition is adaptive vision and roadmapping that connects strategic direction with practical action. A vision clarifies the change a project seeks to create, and the people or systems affected by the problem. Roadmapping translates strategic direction into adaptive next steps while keeping multiple pathways open as learning, evidence, and new opportunities emerge. Depending on what is discovered through market research, experimentation, and scientific inquiry, the idea moves toward a proof of concept, a minimum viable product, applied research, a cooperation project, product innovation, service innovation, process innovation, or a combination of these forms. Teams need awareness of wider system dynamics together with decisions that generate evidence through action. Relevance is sustained through continuous movement between broader understanding and practical execution.

The student project on detecting invasive insects in trees during the larval stage illustrates this dynamic. Its original vision created direction, but the pathway remained open. At different stages, the project shifted attention between technical options, potential users, funding opportunities, sustainability goals, and new application fields. Rather than following a fixed sequence, development advanced through repeated reframing of what kind of value could be created and which form of innovation was most appropriate at that moment. This flexibility expands the initial mission while preserving its broader purpose. Progress emerges through repeated adjustment between long-term direction, new evidence, changing opportunities, and executable next steps.

Artificial intelligence has the potential to strengthen these five conditions when purposefully designed as support for multidimensional judgment rather than narrow optimization. It compares options across technical, economic, human, and societal criteria, makes trade-offs visible, integrates diverse stakeholder perspectives, and highlights hidden externalities. It also supports adaptive roadmapping as circumstances change and reveals when projects drift away from their broader mission.

Under these conditions, innovation remains connected to technical quality, economic viability, human needs, and long-term societal responsibility throughout development. The next question concerns the design of innovation environments: whether relevant knowledge informs decisions and whether people experience real agency in shaping outcomes.

4.3. Strengthening Participation and Agency

Innovation processes depend on knowledge distributed across organizations and society. Participation, therefore, gains meaning when contributions influence decisions and shape outcomes. Agency develops when people experience that their input changes direction and creates visible value. Such influence strengthens ownership, responsibility, and motivation. Where institutions fail to create these conditions, willingness to contribute declines and engagement contracts to formal requirements.

The *How to Invent a Robot* framework responds to this challenge through co-creation, challenge-based learning, and capability development. Participants work on shared problems, explore ideas, and develop artefacts together. In doing so, they improve solutions while building confidence, skills, and agency. Whether this agency becomes real in practice depends on several conditions.

A first condition is early involvement in shaping the problem and the direction of development. Participation gains substance when people affected by a problem can influence decisions while important choices are still open. Approaches such as participatory design, co-creation, and citizen science create pathways for lived experience and external knowledge to enter the process from the start. This often leads to stronger alignment with real contexts of use and greater trust in the resulting solution. Many AI and robotics projects still follow technology-driven pathways, where systems are built from available capabilities and only later introduced into contexts shaped by different needs and constraints. Broader adoption of these approaches would help connect technical development earlier with human realities, situated knowledge, and public trust.

A second condition is actual influence over the shared project and its development. Agency grows when participants experience that their choices matter. In the framework, one of the clearest expressions of this principle is that students choose both the challenge they want to address and the team with whom they want to work. They decide where to invest their effort and with whom they will carry responsibility for the process. Because these choices are theirs, setbacks, conflicts, and difficult feedback are often easier to work through constructively. As the project progresses, their ideas, critiques, and judgments inform concepts, prototypes, and strategic priorities through repeated pitching, feedback, and revision. The final outcome reflects their collective learning and shared work.

A third condition is capability growth through real challenges. Participation gains depth when it strengthens the skills people need for future work and responsible innovation. The framework does this by placing students in situations where these abilities are exercised in practice rather than discussed in theory. A clear example is the pitch sequence. Many students begin with vague ideas, weak arguments, and little experience presenting unfinished concepts in public. Through repeated pitches, critical questions, and revision cycles, they learn to structure arguments, communicate clearly, and respond under pressure. Further learning emerges as interdisciplinary teams negotiate different perspectives, share responsibilities, and turn abstract challenges into workable concepts.

This principle extends beyond education. In many enterprise settings, operational work and formal training remain separated. Such separation leaves situated learning opportunities within everyday projects underused. Capability develops not only through technical problem-solving but also through collaboration, communication, feedback, and other human factors embedded in ongoing work. Learning, therefore, benefits from purposeful micro-interventions within daily practice, including reflection routines, coaching moments, structured feedback, and guided experimentation. Organizations thereby achieve current objectives while building future capacity.

A fourth condition is psychological empowerment through mastery experiences. Agency depends partly on whether people see themselves as capable of acting effectively under uncertainty. Self-efficacy develops through repeated experiences of effective action rather than encouragement alone. This dynamic became visible in the robotics summer camp, where children from different backgrounds spent five days investigating questions about robots, designing ideas, building prototypes, presenting results, and reflecting on their progress. Many arrived without prior confidence in robotics. During the camp, they experienced that they could understand how robots work, generate their own ideas, solve problems, and create functioning artefacts. The study found a significant positive increase in robotics self-efficacy after the program, showing how hands-on creation, experimentation, and visible progress strengthened beliefs in personal capability and future engagement with technical challenges (Jäggle et al., 2020).

A fifth condition is structured reflection on participation, action, and collective life. Innovation environments influence project outcomes and the social capacities formed through collaboration. They shape how people learn to think together, respond to uncertainty, and act in situations where no single actor holds the full answer. In periods of rapid technological, ecological, and social change, many individuals experience

complexity as loss of control and retreat into passivity, cynicism, or dependence on authority. Teams, therefore, need opportunities to reflect on how collective life takes form inside the work itself: who was heard, whose knowledge remained absent, where status shaped decisions, how disagreement was handled, and whether responsibility was shared or avoided. Reflection concerns power, plurality, judgment, and the conditions under which people cooperate across differences. Innovation environments also cultivate democratic capacity through these experiences. When people experience genuine participation and see that collective effort influences outcomes, confidence, agency, and trust increase. Under contemporary conditions of uncertainty, societies increasingly depend on innovation environments that strengthen these capacities through everyday practice.

Artificial intelligence tools are most valuable when intentionally designed to strengthen participation and agency. They widen access to relevant knowledge, bring diverse perspectives into development, and connect external experience to early decisions. They make influence more visible when contributions are documented, traceable, and linked to concrete decisions. They support learning through feedback, coaching, simulation, rapid experimentation, and easier access to expert knowledge during real project work. They also lower entry barriers, help people make early progress, and create confidence through visible achievement. Finally, they also support reflection by revealing participation patterns, neglected voices, hidden assumptions, and trade-offs while reducing routine workload and freeing time for dialogue, learning, and judgment.

When these conditions are present, participation moves beyond symbolic involvement and has the potential to become a productive force in innovation. This, in turn, raises a further question: how such conditions are sustained over time, connected across levels, and embedded in everyday organizational and institutional practice through leadership and governance.

4.4. Leadership and Governance as Enabling Conditions

The three principles discussed above require structures that keep them active in everyday practice. Interdisciplinary collaboration, multidimensional relevance, participation, agency, and learning are easily weakened by time pressure, short-term targets, risk avoidance, and routine execution. Leadership and governance shape whether

these qualities disappear under such conditions or remain part of how work is organized across teams, organizations, and institutions.

Within the *How to Invent a Robot* framework, leadership is embedded primarily in the design of the environment rather than in direct control over decisions. Participants work within a clear and stable structure that defines stages, expectations, milestones, and opportunities for feedback, while retaining broad freedom to choose challenges, form teams, develop concepts, and respond to emerging evidence. Direction is shaped mainly through contact with external realities such as stakeholder needs, customer feedback, technical constraints, economic opportunities, and societal considerations rather than through instructor intervention. Leadership, therefore, operates through boundary-setting, psychological safety, and protection of reflection. This approach shares important elements with transformational leadership, including the creation of shared meaning, support for exploration, individual development, and commitment to goals that extend beyond narrow task completion (Bass & Riggio, 2006).

At the project team level, effective guidance helps teams move forward without closing inquiry too early. In the university learning environment, facilitators create this balance through milestones, coaching, pitch moments, and feedback structures, while ownership of the challenge remains with the teams. When projects lose momentum, groups become attached to weak concepts, or disagreement blocks progress, facilitation helps restore dialogue, reconnect the team with the underlying problem, and turn setbacks into learning. In one case, a technically ambitious concept remained attractive to the team until repeated external feedback showed that the proposed solution addressed no urgent user need. Reframing the challenge reopened progress.

At the organizational level, incentives, budgeting rules, reporting systems, staffing decisions, performance metrics, and time allocation shape behavior more strongly than formal mission statements. Organizations frequently express support for creativity while internal systems continue to reward predictability, efficiency, and short-term output. Under these conditions, innovation relies heavily on individual effort rather than supportive structures. Stronger governance redesigns the surrounding conditions so that experimentation, learning, and cooperation across organizational boundaries become realistic parts of normal work. Such redesign places decision authority closer to operational knowledge and creates space for reflection and capability development by reducing routine burdens. It also establishes clearer accountability and role boundaries between human judgment and technical systems. This becomes visible when

organizations introduce artificial intelligence assistants or analytics platforms, while employee evaluation remains tied only to output metrics or hours delivered. New tools enter unchanged systems, and much of their potential remains unrealized.

At the institutional level, public policy shapes education systems, research agendas, labor transitions, infrastructure, standards, and regulatory legitimacy (Nowotny et al., 2001). These frameworks influence which capabilities are developed, which solutions reach society and markets, how risks are governed, and who benefits from technological change. The pace of institutional adaptation often differs from the pace of technological development, widening the distance between new capabilities and collective direction. This dynamic is especially visible in artificial intelligence, where technical systems evolve rapidly while legislation, regulatory capacity, and administrative procedures often move through longer cycles. Regulators who rely on annual disclosures or static compliance reports may confront systems that have already changed. Yeung (2018) highlighted the limits of static oversight when digital systems evolve through changing data, contexts, and forms of institutional integration. These conditions increase the importance of more adaptive forms of governance that remain responsive as technologies and their societal effects continue to change.

Artificial intelligence also becomes part of the infrastructure of organizations and institutions. Its effects depend on the environments into which it is introduced. Existing fragmentation, narrow optimization, exclusion, or unclear accountability are often reinforced under these conditions. Noble (2018) showed how algorithmic systems reproduce and legitimize existing social asymmetries when underlying institutional arrangements remain unexamined. Environments organized around participation, learning, and shared judgment open different pathways of use.

Under appropriate conditions, AI supports translation across domains and helps synthesize complex information. It can highlight emerging patterns, improve coordination across boundaries, and widen access to relevant knowledge. Routine work requires less human effort, creating more space for reflection, learning, dialogue, and higher-value contribution. Meetings that previously ended in confusion or unresolved tension often become more productive when arguments are summarized clearly, decisions are documented, and trade-offs are made visible. In this role, AI strengthens collective intelligence: the capacity of teams, organizations, and institutions to think, learn, and act together.

The importance of enabling conditions extends to policymaking and political governance. Work in science and technology studies has shown that legitimacy depends on expertise as well as on public processes through which societies evaluate knowledge, negotiate risks, and define acceptable futures. Jasanoff (2004) articulated this through the concepts of co-production and civic epistemologies. As technological and social conditions change more quickly than traditional regulatory cycles, more adaptive forms of governance become increasingly important.

Artificial intelligence can contribute to such adaptation when systems are intentionally designed to help institutions detect emerging developments early, identify where existing rules no longer fit current practice, and shorten the time between new evidence and regulatory response. It may also support continuous monitoring, faster synthesis of expert and stakeholder input, and more timely review of oversight frameworks. Human judgment remains central in interpreting evidence, weighing trade-offs, resolving conflicts, and deciding how rules should change.

The observations in this article, therefore, point beyond the question of how artificial intelligence should be governed. They also direct attention to how democratic institutions might redesign leadership, expertise, and governance so that societal transformation is steered in alignment with technological developments and economic realities. These developments simultaneously reshape the role of human capability. David Autor (2015) argued that as routine activities become increasingly codified or automated, greater value is attached to judgment, creativity, communication, contextual understanding, and responsibility for consequences.

This creates an additional responsibility on leadership and governance: designing productive relationships between technical systems and human development. Institutional choices influence whether automation narrows human roles to forms of supervision or strengthens conditions for learning, agency, and collective progress. Artificial intelligence becomes one possible instrument within this broader task when it is aligned with these aims. The central question, therefore, concerns how environments are designed so that technological progress, human capability, and societal responsibility develop together.

5. Conclusion and Outlook

This article developed the argument that innovation depends on the quality of the environments in which people think, decide, and create together. Many limitations associated with engineering-driven innovation emerge before any final technology is built, when problems are framed too narrowly, when differences between disciplines remain untranslated, when organizational routines reward execution more than understanding, and when reflection lacks protection within everyday work.

The *How to Invent a Robot* framework was presented as a practice-based response to these conditions. It brings together insights from engineering, design, education, management, and the social sciences in an approach that keeps problem framing, collaboration, learning, and decision-making open to revision throughout the innovation process. Three guiding principles structure the framework: productive interdisciplinary collaboration, sustained alignment between technical feasibility, economic viability, human needs, and societal responsibility, and meaningful participation that strengthens agency, learning, and legitimacy. Leadership and governance determine whether these principles become part of everyday practice.

The growing integration of artificial intelligence increases the importance of these questions. As AI becomes embedded in workflows, existing strengths and weaknesses within organizations and institutions are amplified. Weak settings often reproduce fragmentation, narrow optimization logics, and persistent problems of exclusion and accountability. In stronger settings, AI can enhance coordination, broaden access to knowledge, and support reflection and collective intelligence. The decisive issue concerns how such conditions are designed, governed, and continuously improved around technological systems.

Several avenues for future work remain open. The framework requires broader empirical validation across organizational, educational, entrepreneurial, and public-sector settings. Core constructs such as agency, multidimensional relevance, reflective capacity, and collective intelligence require further operationalization and measurement. Comparative studies could examine which structural conditions consistently improve innovation outcomes under different institutional logics. The role of AI as infrastructure for collaboration and governance deserves dedicated investigation, particularly in relation to participation, accountability, and democratic legitimacy. Future development of the framework should integrate sustainability more directly into everyday decision routines so that ecological and social responsibility become part of ongoing practice.

Taken together, the article directs attention to the environments in which engineering innovation unfolds. The broader implication is that more effective, sustainable, and socially relevant forms of technology development are more likely to emerge where collaboration, learning, and agency are actively supported.

Bibliography

Autor, D. H. (2015). Why are there still so many jobs? The history and future of workplace automation. *Journal of Economic Perspectives*, 29(3), 3–30.

Bass, B. M., & Riggio, R. E. (2006). *Transformational Leadership* (2nd ed.). Lawrence Erlbaum Associates.

Blikstein, P. (2013). Digital fabrication and ‘making’ in education: The democratization of invention. In *FabLabs: Of Machines, Makers and Inventors* (pp. 1–21).

Jäggle, G., Lammer, L., Wiesner, J.-O., & Vincze, M. (2020). Towards a Robotics Self-Efficacy Test in Educational Robotics. In *Constructionism 2020 Papers* (pp. 584–597).

Jäggle, G., & Lammer, L. (2026). Teaching Future Engineers through Interdisciplinary Collaboration: A Case Study on Competence Development for Sustainable Innovation. *Proceedings of ICL 2025*, Springer, in Publication.

Jasanoff, S. (Ed.). (2004). *States of Knowledge: The Co-Production of Science and Social Order*. Routledge.

Lavado-Anguera, S., Velasco-Quintana, P.-J., & Terrón-López, M.-J. (2024). Project-Based Learning (PBL) as an Experiential Pedagogical Methodology in Engineering Education. *A Review of the Literature. Educ. Sci.*2024, 14, 617.

Leonardi, P. M. (2011). When flexible routines meet flexible technologies: Affordance, constraint, and the imbrication of human and material agencies. *MIS Quarterly*, 35(1), 147–167.

Lima, R. M., Dinis-Carvalho, J., Sousa, R. M., Alves, A. C., Moreira, F., Fernandes, S., & Mesquita, D. (2017). Ten years of project-based learning in Industrial Engineering and Management at the University of Minho. In A. Guerra, R. Ulseth, & A. Kolmos (Eds.), *PBL in Engineering Education: International Perspectives on Curriculum Change* (pp. 33–51).

Noble, S. U. (2018). *Algorithms of Oppression*. NYU Press.

Nowotny, H., Scott, P., & Gibbons, M. (2001). *Re-Thinking Science: Knowledge and the Public in an Age of Uncertainty*.

Rittel, H. W. J., & Webber, M. M. (1973). Dilemmas in a general theory of planning. *Policy Sciences*, 4(2), 155–169.

Simon, H. A. (1996). *The Sciences of the Artificial* (3rd ed.). MIT Press.

Suchman, L. (2007). *Human-Machine Reconfigurations: Plans and Situated Actions* (2nd ed.). Cambridge University Press.

Xu, L. (2025). Innovative interdisciplinary models in engineering education: Transforming practices across global universities. *Engin Edu Rev*, 2025;2(3):129-144.

Yeung, K. (2018). Algorithmic regulation: A critical interrogation. *Regulation & Governance*, 12(4), 505–523.