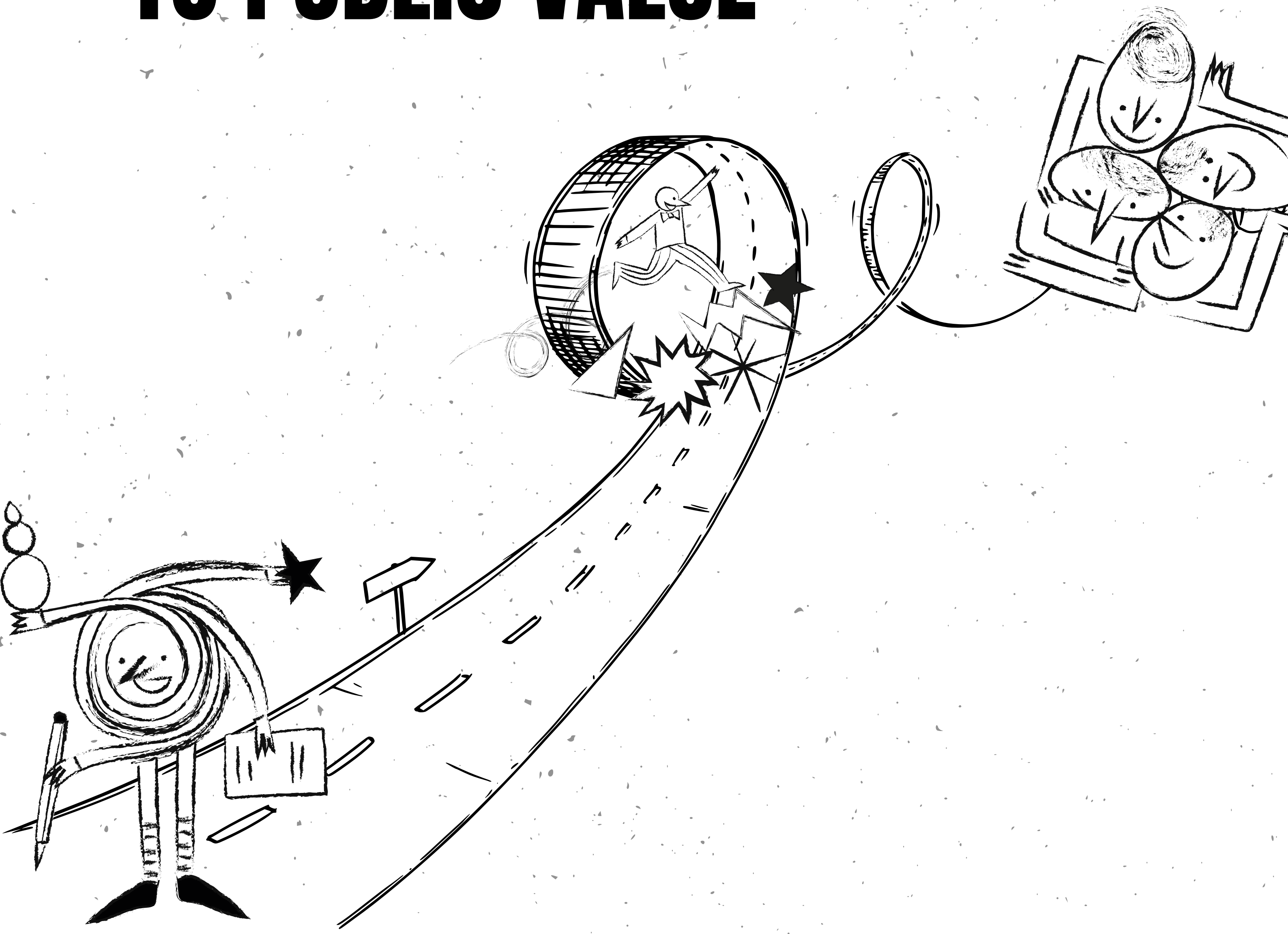
ATTRACT
Socioeconomic Studies

FROM BREAKTHROUGHS TO PUBLIC VALUE



THE SOCIO-ECONOMIC CONTRIBUTION OF ATTRACT

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ABSTRACT

This compendium synthesises the findings of the eight Socio-Economic Studies (SES) projects carried out as part of Phase II of the ATTRACT initiative, a European Union-funded programme supporting breakthrough innovation in deep tech.

While ATTRACT focused on enabling early-stage scientific research, the SES cluster addressed the equally vital question of how such innovation can generate long-term, inclusive public value.

Through interdisciplinary investigations ranging from behavioural psychology to legal infrastructure and entrepreneurial learning, the SES consortium revealed that innovation outcomes are shaped as much by people, institutions, and relationships as by technological breakthroughs.

The projects challenged traditional metrics of success, such as patents or spin-offs, by foregrounding mindsets, diversity, collaboration, and systemic transformation as essential drivers of impact.

The eight SES projects are: **ABC4E**, **EMDOI**, **NEXT-GEN-TECH-ED**, **CORE**, **ExSACT**, **CASEIA**, **COMPUTE IMPACT**, and **NEXT**. Each contributes unique insights and practical tools to improve how innovation ecosystems function, whether through behavioural training programmes, legal templates, entrepreneurship education, or new evaluation frameworks.

Together, they provide an evidence-based roadmap for designing more innovative, inclusive, and adaptable European research and innovation systems. This compendium brings these lessons to the forefront, providing strategic guidance for policymakers, funding agencies, research institutions, and innovation intermediaries seeking to enhance Europe's capacity for mission-driven science and socio-economic impact.

INTRODUCTION

Europe stands at a critical juncture in its approach to scientific and technological innovation. The ATTRACT Phase II initiative, part of the European Union's Horizon 2020 research and innovation framework, was launched to stimulate early-stage, high-risk tech research. However, alongside this technical endeavour, an equally ambitious question emerged: how can scientific breakthroughs create meaningful public value?

The Socio-Economic Studies (SES) consortium was established to explore this question. Through eight coordinated projects, the SES cluster examined the human, institutional, and systemic conditions that either facilitate or hinder the successful transformation of research into socio-economic impact.

Rather than assessing success through a narrow lens of outputs such as patents, spin-offs, or licensing deals, the SES initiative reconceptualised innovation as a dynamic, interconnected process involving mindset shifts, capacity building, behavioural change, institutional learning, and collaborative action.

By investigating what happens behind and beyond the lab bench, the SES studies provide an evidence-based blueprint for strengthening Europe's innovation ecosystems.

This compendium serves as an integrated introduction to these eight SES projects. Each chapter presents findings, policy recommendations, and tools that advance our understanding of the socio-economic dimensions of research and innovation. What follows is a synthesis of the overarching insights, along with an introduction to the individual contributions of the eight studies.

FROM OUTPUT TO OUTCOME

Traditional research assessments tend to emphasise measurable outputs, such as technological readiness levels, the number of patents, or company formations. While important, these indicators capture only a limited picture of innovation.

The SES consortium instead foregrounded outcomes that are often overlooked: new capabilities, behavioural changes, knowledge flows, and institutional transformations. These factors are essential in determining whether public investment in research yields long-term, inclusive impact.

Two projects in particular, **COMPUTE IMPACT** and **CASEIA**, challenged the primacy of short-term commercial metrics. **CASEIA** explored the long-term value of three ATTRACT Phase I projects, revealing that even so-called technical failures contributed to knowledge development, industrial learning, and future collaborations.

COMPUTE IMPACT focused on AlphaFold, a major scientific breakthrough, to illustrate how open infrastructure, rather than proprietary

outputs, can catalyse system-wide innovation.

The project argued that research infrastructures act not only as service providers but also as platforms for sustained, distributed value creation.

The clear policy implication is that funders and institutions must broaden their frameworks for evaluating innovation, integrating dimensions such as serendipity, spillovers, skill development, and ecosystem capacity.

MINDSETS THAT ENABLE INNOVATION

At the heart of every scientific breakthrough are individuals and teams. Yet traditional innovation policy often neglects the psychological and behavioural dimensions of collaboration. The SES projects **ABC4E** and **EMDOI** addressed this gap by focusing on how mindsets, attitudes, and inclusion shape the success of research efforts.

ABC4E implemented a behavioural training programme across five European research institutions. Drawing on psychological models, the project found that increased psychological flexibility correlated with higher engagement in interdisciplinary and cross-sectoral collaborations.

Participants demonstrated a greater openness to working with industry and attending external events. These behavioural changes laid the groundwork for more sustained innovation practices.

EMDOI investigated how entrepreneurial intentions and inclusive team practices influence the commercialisation pathway. It found that while some project leaders had strong entrepreneurial aspirations, institutional and team-level dynamics often limited follow-through. Diversity emerged as a critical, though initially under-recognised, driver of innovation. Projects that engaged users and included diverse perspectives early in the design process were more likely to pursue inclusive, outward-facing innovation trajectories.

Together, these studies highlight that the success of open innovation requires not only institutional alignment but also behavioural readiness and team diversity. Training in psychological flexibility and inclusive design should become an integral part of innovation support structures.

ENTREPRENEURIAL LEARNING IN SCIENTIFIC CONTEXTS

Europe's academic institutions are rich in scientific expertise but often struggle to translate this potential into entrepreneurial outcomes. Two SES projects, **NEXT-GEN-TECH-ED** and **EMDOI**, examined how scientists learn to become entrepreneurs and what kinds of support structures are most effective.

NEXT-GEN-TECH-ED introduced the concepts of "seeding" and "soloing" as learning strategies within scientific teams. In the early phases of development, researchers relied on external advice and partner engagement (seeding), while more advanced projects shifted towards experiential, iterative learning (soloing). The study also showed that Entrepreneurial Self-Efficacy (ESE) is not inherent but rather develops through mentorship, exposure to real-world challenges, and supportive team environments.

EMDOI reinforced these findings, showing that entrepreneurial behaviours arise from organised learning ecosystems rather than individual ambition alone. Scientists were more likely to engage in commercialisation when provided with meaningful interaction with users and role models. Importantly, many participants viewed entrepreneurship not as a purely commercial act, but as a means to achieve social and scientific missions.

The implication for policy is clear: entrepreneurship education for scientists must reflect the realities of scientific work. It should be interdisciplinary, experiential, and mission-driven, allowing researchers to explore real-world problems while maintaining scientific integrity.

OPEN INNOVATION & ECOSYSTEM COLLABORATION

Innovation today is increasingly collaborative, relying on complex ecosystems that span institutional, disciplinary, and sectoral boundaries. The SES projects **CORE** and **ABC4E** examined how these ecosystems function and what enables productive collaboration.

CORE studied the distributed nature of the ATTRACT ecosystem, where no single actor dominates. Instead, collaboration emerged from informal relationships, trust, and the bridging roles played by hybrid individuals (such as scientist-entrepreneurs).

The project developed a practical stakeholder mapping toolkit that helped teams identify and engage with overlooked stakeholders. When used in classroom and workshop settings, the toolkit improved network awareness and collaboration strategy.

ABC4E, while focused on individual behaviour, supported **CORE's** ecosystem insights. Its findings indicated that psychological barriers, such as fear of compromise or lack of confidence, can inhibit open innovation. Training programmes that address these biases can significantly increase willingness to engage across boundaries.

Both projects highlighted the frequent tensions between public and private sector reasoning, particularly around intellectual property and timelines.

Managing these tensions transparently and proactively was found to foster creative solutions while avoiding misalignment and missed opportunities.

INSTITUTIONAL & LEGAL INFRASTRUCTURE

Even the most innovative teams cannot thrive without enabling legal and institutional frameworks. The **ExSACT** project addressed the systemic legal and administrative challenges facing research institutions across Europe, particularly those related to public-private collaboration.

Focusing on Slovenia and drawing comparisons with Italy and the Czech Republic, **ExSACT** developed a toolkit comprising legal templates, IP frameworks, and valuation models aligned with EU State Aid regulations. The study revealed widespread ambiguity in the interpretation and implementation of these regulations, often due to a lack of internal institutional guidance. This uncertainty discouraged commercialisation and exposed research organisations to legal risks.

The project also conducted a survey of the ATTRACT community, revealing that while many teams had developed new intellectual property, few had licensed it.

A lack of formal inventor reward systems and inconsistent IP valuation practices were significant barriers to progress.

The recommendation is clear: align legal interpretations across Member States, provide common templates, and enhance governance capacity. Legal clarity and institutional consistency are essential for fostering practical innovation.

RETHINKING IMPACT & EVALUATION

One of the most profound contributions of the SES consortium lies in its critique of how innovation is evaluated. **CASEIA**, **COMPUTE IMPACT**, and **NEXT** collectively argued for a transformation in the way research performance is measured.

CASEIA's impact framework integrates dimensions such as serendipity, spillovers, and skills development, factors that traditional metrics overlook. **COMPUTE IMPACT's** study of AlphaFold underscored the value of infrastructure-enabled innovation, showing how public investment in open data platforms can generate ripple effects across multiple domains. **NEXT** introduced a novel approach to policy experimentation by conducting real-world randomised controlled trials in university-industry collaborations.

These projects demonstrate that policy should be treated as a living experiment, not a fixed plan. Evaluation systems must shift from static outcome measurement to dynamic, ongoing learning. This will require new tools, new mindsets, and new institutional incentives.

CROSS-CUTTING RECOMMENDATIONS

Even though the SES projects took different approaches in their work, exploring various disciplines, methods and themes, they ultimately pointed toward the same underlying message: Europe's success in translating research into tangible impact relies not only on technology, but also on the systems that support it. Rather than offering isolated findings or technical solutions, the eight studies identified structural patterns and common needs within the innovation landscape. This section consolidates those insights, providing a set of cross-cutting recommendations for policymakers, institutions, and educators, grounded in the real-world challenges and opportunities faced by the SES consortium.

FOR EU POLICYMAKERS

The SES findings highlight the need for a broader and more nuanced definition of innovation impact. While traditional indicators such as publications, patents, and TRL (Technology Readiness Level) progression remain useful, they are inadequate for capturing the full range of value generated by research. Multiple projects revealed that behavioural change, institutional learning, collaboration capacity, and inclusivity are equally important forms of impact, even though they often go unnoticed.

Policy frameworks must therefore evolve to acknowledge this complexity. Projects such as **CASEIA** and **COMPUTE IMPACT** have demonstrated that tools and platforms developed within publicly funded infrastructures can produce long-term, system-wide effects that extend well beyond immediate commercialisation. Policymakers should encourage and fund multi-dimensional evaluation frameworks that enable projects to report not only on outputs but also on changes in mindset, network strength, user engagement, and societal benefits.

In parallel, programs should be designed to include built-in opportunities for experimentation, as demonstrated by **NEXT**. By encouraging funding recipients and agencies to test, iterate, and evaluate various approaches, such as in training, stakeholder engagement, or intellectual property management, we can gain valuable insights and enhance policy responsiveness over time. Rather than viewing program design as something static, Horizon Europe and future frameworks would benefit from integrating real-time, adaptive learning processes into their core structure.

In the end, numerous projects have highlighted the need for greater regulatory clarity and alignment across member states. The work of **ExSACT** has shown that even well-designed EU regulations can hinder innovation if interpreted inconsistently at the national level. The European Commission can play a key role in supporting harmonization by providing training and shared templates, particularly in areas like state aid compliance and collaborative research contracts. This approach can help reduce administrative burdens and build confidence among stakeholders.

CROSS-CUTTING RECOMMENDATIONS

FOR RESEARCH INSTITUTIONS

Research institutions are increasingly being asked to do more than just conduct excellent science, but they are also expected to contribute to innovation, regional development, public engagement, and policy making.

However, many of these institutions lack the internal systems and capabilities necessary to meet these expectations effectively. The SES projects provide specific recommendations on how institutions can evolve to better support these broader roles.

First, institutions should focus on building capacity for open innovation. As demonstrated by **ABC4E** and **CORE**, although researchers are often motivated and curious, they frequently lack the necessary tools and support to engage externally. Offering training in psychological flexibility, stakeholder mapping, and early-phase collaboration can greatly enhance researchers' abilities to participate in and lead inter-disciplinary, cross-sector initiatives.

Second, institutions need to formalize and clearly communicate their policies regarding intellectual property (IP), licensing, and contract research, using resources such as those created by **ExSACT**. A lack of internal clarity not only discourages partnerships but also introduces legal risks. Providing templates, valuation frameworks, and transparent reward systems for inventors can help integrate commercialisation as a recognised and supported pathway, while still preserving academic freedom.

Finally, institutions should recognise diversity and inclusion as strategic assets in research and innovation. The **EMDOI** study showed that diversity fosters innovation only when it is purposefully integrated into team formation, problem framing, and user engagement.

To support this, institutions can review their hiring practices, provide training in research design, and evaluate criteria to ensure that diverse perspectives are not only included but also empowered to influence outcomes.

CROSS-CUTTING RECOMMENDATIONS

FOR EDUCATORS & INNOVATION INTERMEDIARIES

One of the most consistent results across the SES studies was that entrepreneurship education for scientists needs a distinct approach, one that must consider the complexity, uncertainty, and ethical obligations inherent in scientific work. Programs that simply adapt business school models to research environments, often do not resonate with scientists and, in some cases, may even deepen their feelings of alienation from commercialisation.

NEXT-GEN-TECH-ED and **EMDOI** outline a clear roadmap for improvement in education. Educational programs should focus on experiential learning, interdisciplinary approaches, and real-world problem-solving. This allows researchers to engage with commercialisation not as a departure from science, but as a way to enhance its societal value. Training should provide exposure to end-users, role models, and real-world constraints, while also reinforcing essential scientific values such as rigor, openness, and social impact.

Intermediaries on the other hand, such as technology transfer offices and innovation agencies, must also adapt. Instead of merely serving as gatekeepers or facilitators of transactions, they can function as coaches, networkers, and translators, helping teams navigate the complex human, legal, and commercial aspects of innovation.

As demonstrated in the **NEXT** project, even light-touch interventions, such as coaching or redesigning outreach efforts, can significantly increase engagement and impact when implemented with intention and responsiveness.

These recommendations highlight a shift from a transactional model of innovation policy to a transformational one. This new approach values human capability, systemic learning, and inclusive design just as much as market delivery. The SES consortium does not advocate for abandoning commercialisation or scientific excellence, but instead, it encourages embedding these elements within ecosystems that are intelligent, reflective, and fair.

CONCLUSION

The eight projects within the SES consortium, as part of ATTRACT Phase II, were not just independent research efforts, but they represented a coordinated initiative aimed at understanding the human, institutional, and systemic factors that determine whether breakthrough science creates public value.

Together, these projects present a compelling narrative that challenges traditional assumptions, suggests actionable frameworks, and establishes a foundation for a more integrated, intelligent, and responsive innovation system in Europe.

As Europe enters a new era of mission-driven innovation to address challenges such as climate change, health equity, and digital transformation, the insights from SES are particularly relevant.

These missions require not only improved scientific approaches but also the development of robust systems that integrate various disciplines, connect different sectors, and remain adaptable to uncertainties.

SES demonstrates that these systems cannot be created through funding alone and that they must be intentionally designed with a focus on capabilities, mindsets, and governance.

The vision that emerges is clear:

- Build inclusive and adaptive ecosystems, where innovation is measured by both excellence and engagement;
- Learning, behaviour change, and ecosystem capacity should be viewed as strategic outcomes, rather than side effects;
- Incorporate flexibility and experimentation into both program design and evaluation;
- Empower scientists, institutions, and policymakers, by providing them with the tools they need to lead effectively across boundaries.

In short, SES projects did not just assess the impact, but it redefined it. It demonstrated that the socio-economic value is not a byproduct of scientific advancement, but rather the result of intentionally designed systems that nurture, translate, and extend knowledge into tangible benefits for the real world.

The next step is to carry these insights forwards, ensuring that the European innovation agenda evolves not only in terms of funding but also in how it defines and facilitates impact. The SES consortium provides both a knowledge base and a community of practice that is ready to support this evolution.

ABC4E: A TRAINING TO UNLOCK COLLABORATION ACROSS DISCIPLINES AND ORGANIZATIONS IN RESEARCH SETTING

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Unlocking Innovation Attitudes. The **ABC4E project** represents a pioneering effort to improve the impact of research on society. Biases such as the "Not Invented Here" (NIH) syndrome and the "Not Sold/Shared Here" (NSH) syndrome hinder effective knowledge sharing and collaborative behaviours, which are essential for successful science-driven innovation and the transfer of research results to society.

ABC4E aims to promote open innovation behaviours among researchers in research institutions and science-driven initiatives by providing behavioural training to enhance psychological flexibility among scientists. Indeed, psychological flexibility leverages perspective-taking, and previous research has found that perspective-taking enabled by re-categorisation interventions could significantly reduce biases such as 'not invented here' and 'not shared here'. The core challenge of the project was to integrate open innovation education with psychological training using **Acceptance and Commitment Therapy (ACT)** as a framework for psychological training.

The **ABC4E** research group employed a rigorous methodology and utilised the Action Research Innovation Management Framework to address biases and facilitate knowledge exchange in research settings. Following a series of exploratory interviews, we have conducted five iterations of the project, refining our approach and content with each cycle. We have placed a particular emphasis on integrating the **ACT** matrix and perspective-taking techniques to address internal obstacles and biases.

This effort has resulted in the development of a comprehensive training protocol and a companion booklet containing follow-up activities. To assess the impact of our interventions, we have crafted two specific surveys to measure changes in psychological flexibility and shifts in open innovation attitudes and behaviours. These surveys were administered before and after each iteration, and they showed how the training positively impacted the psychological flexibility of the participants, resulting in an improvement of specific open innovation behaviours like "attending conferences that are not relevant to one's own discipline".

The ability to collaborate effectively is not simply a matter of organisational structure or access to resources; it requires a fundamental shift in mindset.

Psychological training that targets psychological flexibility can lead to this transformation, encouraging scientists to adopt behaviours that are crucial for interdisciplinary work.

Psychological flexibility is instrumental in helping scientists overcome biases that limit collaboration, such as the "Not Invented Here" (NIH) and "Not Sold Here" (NSH) syndromes. These syndromes reflect a resistance to external ideas and a reluctance to share internal knowledge, both of which hinder scientific progress in open, interdisciplinary settings.

The **ABC4E** project demonstrates how structured interventions designed to enhance psychological flexibility can dismantle long-standing barriers to collaboration, facilitating more productive and innovative scientific endeavours.

In particular, **ABC4E** has developed a training based on Acceptance and Commitment Therapy (ACT), as ACT training focuses on developing psychological flexibility as a core skill. The ACT model is already used not only in clinical settings but also in high-performance environments, such as distress management, workplaces, and sports. However, no one has ever developed an ACT training specifically for scientists, and the **ABC4E** effort marks its first application with scientists. The training program introduced techniques to increase scientists' openness to new perspectives, fostering collaboration across disciplinary and organisational boundaries.

Figure 1. A moment of the training in Genova (pic. 2023).

Participants reported an increased ability to work with industry partners, interact within electronic networks, and attend interdisciplinary conferences. These activities are central to the open innovation framework, which emphasises the free exchange of knowledge between academia, industry, and other stakeholders.

In synthesis, psychological training that is able to increase the researchers' psychological flexibility with ACT has the potential to profoundly transform scientific collaboration by addressing the cognitive and emotional barriers that impede open innovation.

How does psychological flexibility influence attitudes towards innovation?

Psychological flexibility represents an individual's ability to fully live in the present moment, manifesting human awareness, and adapt their behaviours according to circumstances while pursuing their goals and values when possible. For humans to fully experience their individual journey, it is necessary for them to develop psychological flexibility. In contrast, psychological inflexibility constitutes a person's maladaptive behavioural repertoire. It reflects a tendency to respond rigidly and automatically to both internal (subjective experiences occurring within everyone's mind) and external (objective, observable) experiences, limiting the capacity to adapt effectively to life challenges and pursue a meaningful life aligned with their values.

Acceptance and Commitment Therapy is an evidence-based psychological intervention that uses acceptance, mindfulness, and behaviour modification strategies to enhance the "psychological flexibility" of each individual. ACT hypothesises that the main psychological processes responsible for psychological inflexibility are cognitive fusion and experiential avoidance.

ACT in a Nutshell - six core processes that lead to individual psychological flexibility

Acceptance and Commitment Training is based on the six core processes highlighted by Acceptance and Commitment Therapy, including contact with the present moment, acceptance, defusion, perspective taking, value clarification, and committed action, and has been shown to be effective in many professional settings. ACT training teaches people that thoughts, emotions, physical sensations, memories and impulses arise naturally during the working day and that these feelings do not need to be eliminated or avoided. This approach suggests that voluntary exposure to psychological experiences is healthier and ultimately enables the worker to be more effective.

ACT training provides new contexts for experiencing 'negative' feelings so that they are perceived as less toxic and do not need to be avoided, thus enabling people to perform their work appropriately and effectively. ACT training promotes defusing processes to help employees become aware of their unhelpful thoughts and to allow them to engage in productive action in the presence of these cognitive barriers.

For example, if an experienced manager is asked to attend a company training session, he might claim that he is a veteran and does not need anyone to tell him how to do his job. This person may become fused with their own self-description, which could impact their level of psychological flexibility and potentially affect their future job performance.

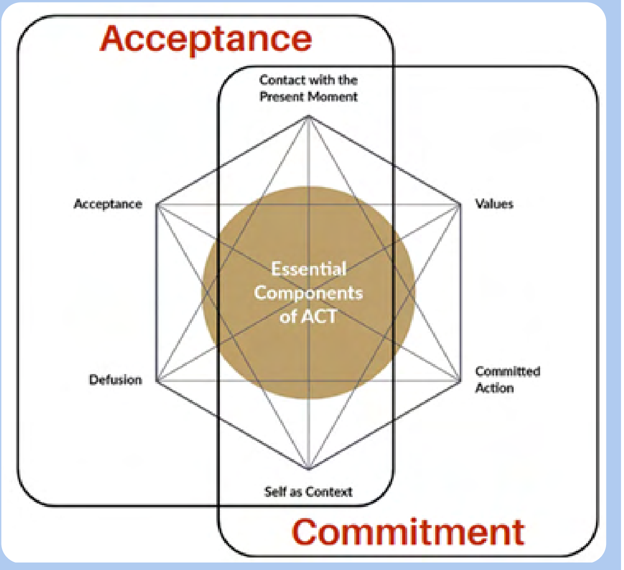

Figure 2. The core dimensions of psychological flexibility. Adapted by the authors, inspired by "Acceptance and commitment therapy: Model, processes and outcomes" by Hayes et al. (2005)

ACT training invites people to 'step back', to disengage from useless self-descriptions and to take a broader view of who they are. Users learn to recognise that they are something greater than the roles they play, the titles they hold, the emotions, feelings, thoughts or impulses they experience, but that these are simply experiences that are part of their lives. This perspective allows the worker to behave more flexibly in the presence of these psychological events, which, if not correctly managed, could hinder productivity or increase stress levels [42].

Additionally, value clarification in ACT training encourages employees to explore the significance of their lives and the choices they make. For example, when a doctor expresses his sincere motivation to reduce suffering in his community and thus recognises that this purpose can guide his choices about how to practice his profession, he is clarifying his values and linking these verbalisations to his professional commitment.

The ACT model suggests that such clarification of vocational and professional values can enhance psychological flexibility in the workplace.

What impact does ABC4E have on scientific progress, and what learnings?

Scientists display varying degrees of openness and cultivate diverse attitudes towards open innovation, which affects how their research impacts society, how it is disseminated, and how new stakeholders are involved in the research process. The ability to collaborate effectively not only improves the quality and speed of scientific discoveries but also broadens the scope of research by incorporating diverse perspectives. In this way, psychological training that improves collaboration skills can be seen as a catalyst for scientific advancement, enabling more dynamic and impactful research outcomes.

The project demonstrated that participants who developed higher levels of psychological flexibility through targeted training were more capable of engaging in collaborative behaviours essential to open innovation. This flexibility enabled scientists to navigate the emotional and cognitive barriers that often inhibit cross-disciplinary and cross-sector knowledge sharing more effectively. In open innovation settings, particularly within the ATTRACT initiative, where breakthroughs depend on the seamless flow of knowledge among academia, industry, and other stakeholders, psychological flexibility has become a critical asset. The implication here is clear: fostering behavioural flexibility among scientists can directly enhance their ability to collaborate effectively and push the boundaries of innovation.

This realisation led to another significant lesson: targeted interventions, such as Acceptance and Commitment Therapy (ACT), can meaningfully influence specific behaviours critical to innovation. The training helped participants not only in theoretical knowledge but also in practical, observable behaviours such as engaging in industry-academia networks, attending interdisciplinary conferences, and fostering collaborative research activities.

However, the project also highlighted that more complex behaviours, such as applying for patents, may take longer to develop, underscoring the need for sustained efforts. This speaks to the necessity of designing interventions that are long-term and goal-specific rather than relying on short-term fixes or generic training programs. The psychological dimensions of innovation, particularly the individual-level readiness to collaborate, require ongoing attention and support.

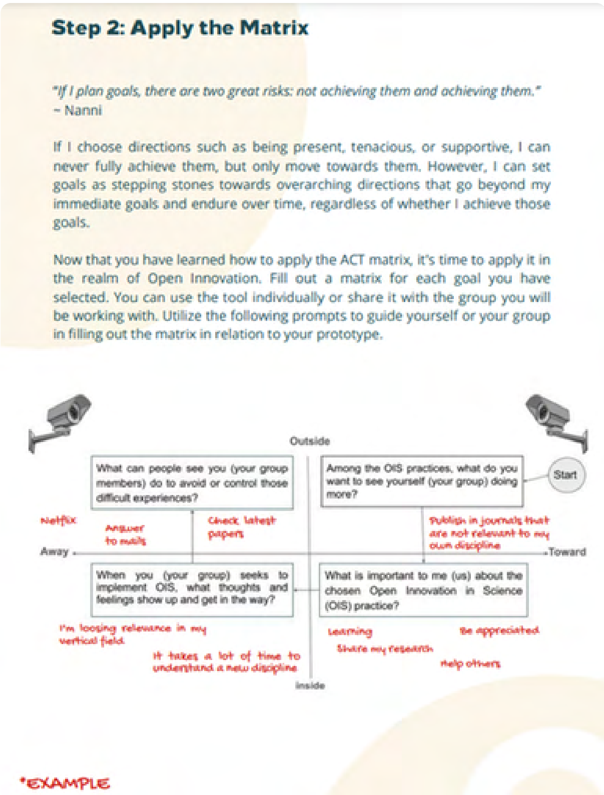

Figure 3. The ACT matrix was used during the training. Researchers are trained to identify and accept negative thoughts and behaviours that arise while trying to pursue open innovation behaviours. The matrix trains researchers to continue acting towards the desired open innovation behaviours despite the presence of negative thoughts and behaviours.

Moreover, the project shed light on the value of cross-sector engagement as a driving force for innovation. Participants who improved their psychological flexibility were more inclined to engage with industry professionals, interact in electronic networks, and participate in the joint supervision of postgraduate students.

These behaviours are pivotal for building cross-sectoral bridges, which are essential to translating academic research into practical, marketable technologies.

Based on the lessons learned from the **ABC4E** project, we envision a key recommendation for policymakers to incorporate behavioural training into research funding programs. Initiatives like ATTRACT, which rely on interdisciplinary collaboration, can benefit greatly from including psychological training, such as ACT, as part of their funded activities. Enhancing the psychological flexibility of scientists will better equip them to navigate the complexities of open innovation, leading to more effective collaborations and innovative outcomes. Furthermore, long-term support is essential. While short-term interventions can bring about immediate improvements, complex behaviours like patent applications, spin-off founding, and deep interdisciplinary collaborations require more extended observation periods and sustained follow-up. Policymakers should, therefore, allocate resources to ensure that participants in open innovation programs receive the necessary long-term backing to develop their collaborative skills fully.

Figure 4. An ABC4E booklet distributed during an ABC4E training session. The training was activated by the Research Institute's Knowledge Transfer Office to support its Researchers research transfer.

SOCIO-ECONOMIC IMPACT THROUGH THE LENS OF THE ATTRACT INITIATIVE

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THE ATTRACT EXPERIMENT & THE CASEIA SOCIO-ECONOMIC STUDY

As one of ATTRACT's socio-economic studies, the **Comparative Analysis of Socio-Economic Impact (CASEIA)** project developed an analytical framework and methodology for better understanding the socio-economic impact of ATTRACT. On the basis of in-depth interviews with key stakeholders and drawing on a consolidated set of analytical concepts upon which ATTRACT was founded, **CASEIA** examined three case studies, with an emphasis on identifying and understanding the consequences of ATTRACT intervention. These case studies not only tell us about the ways in which ATTRACT fostered a range of socio-economic impacts, but also have the potential to inform the planning and assessment of future ATTRACT interventions, or similar programmes of work.

Background research and interviews examined the actor-network of each case study, with relationships between these actors mediated by relationships such as funding, knowledge, data, intellectual property, governance structures, skills transfer, collaboration, and value chains. Against this background, **CASEIA** mapped six key dimensions of socio-economic impact:

Serendipity: Have there been applications of technology outside their original intended use?

Spillovers: Has knowledge and capability been transferred across different organisations in each case study? How can this be characterised?

Spin-offs: Have there been industry applications, intellectual property generation, or economic outcomes?

Social structures: Were new relationships, collaborations, or partnerships built?

Skills and learning: What skills have been developed? What learning has taken place? What new capabilities have been built?

Broader socio-economic impact: Looking beyond the other analytical dimensions, what are the broader socio-economic impacts?

CASE STUDIES

Our case studies compare two ATTRACT Phase 1 projects. The first, OptoGlass3D, was a business-led consortium whose objective was to develop materials and techniques for a commercial glass manufacturing application.

The other case study, Scintiglass, was university-led, with the aim of developing a new component for high-energy physics at European research infrastructures (ERIs). While both projects received Phase 1 support, only OptoGlass3D went on to develop commercial applications and received ATTRACT Phase 2 support.

As a third case study, we also examine a non-ATTRACT project closely related to Scintiglass. This comparator case is within PANDA (proton-antiproton annihilation at Darmstadt), a large-scale fundamental physics project housed within an ERI. We identified the sub-project PANDA EMC as our comparator object. This sub-project is tasked with developing the electromagnetic calorimeter (EMC, a detector) for PANDA based on scintillating crystals. Scintiglass aimed to develop glass scintillators for calorimetric detectors. From an innovation network perspective, the Scintiglass project fulfilled an R&D

role within the technological and institutional context of PANDA EMC. We assess the impact of PANDA using the same fieldwork process and analytical framework as the two ATTRACT projects. The contexts of the three cases are shown in Figure 1.

ATTRACT support. Within this new constellation of firms, we observed a strongly project-based start-up working culture that was closely aligned with markets and driven by investment in R&D. R&D activity constitutes a third of Glassomer's personnel time.

Variable	OptoGlass3D	Scintiglass	PANDA EMC
Received ATTRACT Phase 1 funding	Yes	Yes	No
Received ATTRACT Phase 2 funding	Yes	No	No
ATTRACT student roles	Yes	No	No
Business-led	Yes	No	No
ERI-led	No	Yes	Yes
Commercialisation outcomes	Yes	No	Yes
Knowledge/capabilities outcomes	Yes	Yes	Yes

Figure 1. Variables describing the comparative contexts of the three cases studied.

OPTOGLASS3D

The OptoGlass3D consortium consisted of two German private companies: Glassomer and Nanoscribe. It was thus distinct from Scintiglass in that it did not have ERI partners or stakeholders. The relation to ATTRACT was, therefore, primarily based on its novel production techniques rather than any direct relation to an ERI environment. The project used two-photon polymerisation to structure glass as if it were a polymer. The challenge of the OptoGlass3D project was to develop and commercialise a material that makes this technique compatible with 3D printing, allowing users to produce glass components in shapes that cannot be achieved otherwise. The technology has the potential to generate significant societal benefits, for example, in public healthcare, through integrated glass lenses on optical fibres used in medicine. Being an open-ended technique, its fields of application, and hence its impacts, are in the hands of users.

OptoGlass3D had a wide range of socio-economic impacts. Firstly, the organisational structure of OptoGlass3D, interviews made it clear that the collaboration would not have emerged without

The project also had significant knowledge impacts. The industrial and social significance of the technological progress made by the consortium led to a cover article in Nature Communications (Kotz, 2019). OptoGlass3D has produced new knowledge that has the potential to inform global technology development. Internally, knowledge production also entailed knowledge spillovers across the consortium firms and their supply chains.

When seen through the lens of the ATTRACT experiment in technological Serendipity, OptoGlass3D can be seen as a case of Stephanian Serendipity by design. According to Yaqub, there are four types of Serendipity (Yaqub, 2017). Stephanian Serendipity occurs when a non-targeted line of enquiry leads to a solution waiting for a problem. OptoGlass3D made the conscious choice to market a technique (a solution) and not an application, leaving the matching of the solution to a problem to the user. This led to the most significant economic impact of OptoGlass3D; viz.: it made a disruptive technology commercially available to a wide field of users and applications. The societal and financial implications of this are still unfolding.

SCINTIGLASS

Scintiglass aligned well with the ATTRACT vision of ERI-driven cross-sectoral collaboration. The lead partner was the University of Gießen. Other higher education partners were the universities of Milan and Vilnius. CERN represented the ERI sector in the collaboration. This network was previously embedded in the ERI environment through the CERN Crystal Clear collaboration for scintillating detectors. Additionally, Scintiglass included Preciosa Ornela (Figure 2), a glass seed-bead manufacturer with product development capabilities.

Scintiglass aimed to develop a cheaper, easier alternative to the lead tungstate crystals currently used for calorimetry in high-energy physics, such as in the PANDA EMC. Glass uses more affordable raw materials and, being amorphous, does not require laborious and time-intensive crystal-growing laboratories. Another application envisioned for the glass scintillators was PET scanners (positron-emission tomography) for visualising metabolic processes and blood flow in medicine. Scintiglass aimed to scale up from lab prototypes to series production.

Preciosa experimented with recipe and production protocols, producing small samples of materials with desirable scintillation qualities. However, scaling-up failed once the ingots reached 300g – well below a usable size for high-energy physics calorimetry or PET, and no further progress was made in this direction.

Thus, despite being structurally and institutionally closely aligned with the ATTRACT vision, Scintiglass did not achieve its primary scientific or technological aims, nor did it lead to any spin-offs or commercialisation. However, there were substantive knowledge spillovers. Through Scintiglass, Preciosa discovered that the inorganic compound silicon carbide produces desirable oxidisation and reduction.

This encouraged them to experiment with applying inorganic redux to the continuous production of lustre seed beads. In commercial terms, the process was an expensive failure, as it ruined a production kiln; however, Preciosa perceived it as a net positive in terms of learning outcomes. Indeed, skills and learning are the most substantive outcomes of Scintiglass, even if the primary lesson is that the scaling of glass scintillators is not (yet) feasible. Other forms of learning and skills development included learning among PhD students, new suppliers, and new materials, as well as the development of capabilities through the R&D process.

While some positive impacts are evident, the Scintiglass case did not reveal any meaningful Serendipity. Using the taxonomy of Yaqub, the Preciosa redux experiment was an excursion into Walponian Serendipity, where a targeted line of

Figure 2. The Preciosa Ornela factory in Desná, Czech Republic

enquiry (glass scintillators for ERIs) was applied to a different problem (continuous production of lustre seed beads) (Yaqub, 2017). Since the constant production method failed, Preciosa returned to its established batch production method.

PANDA

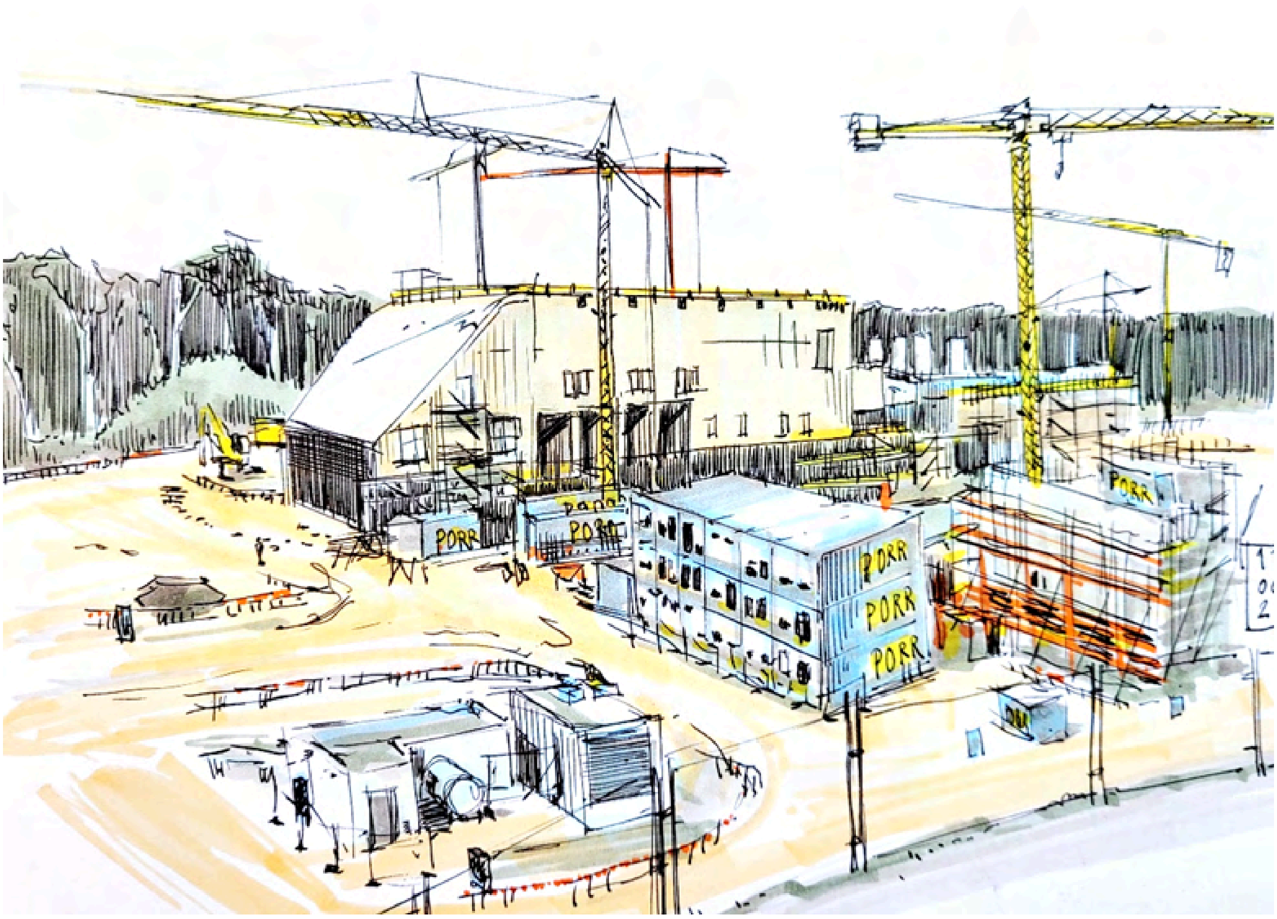

Figure 3. Part of the FAIR construction site in Darmstadt, Germany

Unlike the two ATTRACT cases, PANDA is a large-scale fundamental physics project based at the ERI, the Facility for Antiproton and Ion Research, FAIR (Figure 3). As our comparator object, we identified the ongoing sub-project PANDA EMC, which is tasked with developing the electromagnetic calorimeter (EMC) for PANDA. It is coordinated by the same working group at the University of Gießen as Scintiglass. Like Scintiglass, it is the fruit of the CERN Crystal Clear collaboration.

The manufacturing partner, Crytur, is a sister company to Preciosa Ornela. The many parallels between the PANDA EMC sub-project and Scintiglass make PANDA a suitable do-nothing counterfactual. Importantly, the two cases differ in their funding models and business plans. The household budgets of the collaborating institutions support PANDA EMC. In terms of business models, the PANDA calorimeter 'leaves it to chance', being 'orphaned' in the sense of Chesbrough (Chesborough, 2010). Scintiglass was supported by ATTRACT and, therefore, sought to match innovation to a business plan.

There have been no direct spin-offs from the development and production of the lead tungstate crystals for PANDA EMC. One related patent was registered (Patentnr. DE 10 2009 023 917 A1, 2010).

However, it has since been withdrawn as it did not yield economic results – possibly since there are few applications for lead tungstate crystals. The academic culture in which PANDA EMC is embedded is not conducive to commercial exploitation, and its overall impact profile is typical for ERIs:

there was no Serendipity nor commercialisation agenda. The impact is felt in the areas of spillovers, skills development and network development. Efforts to better determine the impact of PANDA would need to include dimensions not included in the ATTRACT paradigm – these being the ultimate impacts for science and society that may result from the successful epistemic mission of PANDA.

COMPARATIVE ANALYSIS AND THE EFFECT OF ATTRACT

Only OptoGlass3D presented significant positive impacts in each of the six analytical dimensions used for the study. For both Scintiglass and the PANDA project, with which it is closely related, the primary positive impacts were in the areas of knowledge production, knowledge spillovers, and skills development, as shown in Figure 4:

Dimension	OptoGlass3D	SCINTIGLASS	PANDA EMC
Serendipity	High	None	None
Spin-offs	High	None	None
Spillovers	High	High	Some
Skills and learning	High	High	High
Social structure development	High	Some	None
Broader social impact	High	Some	Some

Figure 4. The six dimensions of impact in our three cases.

OptoGlass3D and Scintiglass provide a helpful contrast. The two ATTRACT cases illustrate the different cultures, processes, and roles played by ERIs and firms within the ATTRACT model. OptoGlass3D was led by and oriented towards industry. Being embedded in industry cultures and incentives, it ultimately had an impact on the industrial sector. Scintiglass was more closely tied to the world of ERIs and universities, and here, the support provided by ATTRACT was insufficient to bridge the innovation gap. OptoGlass3D had a far broader and greater set of impacts than Scintiglass in relation to the key metrics set out by the ATTRACT framework.

On the other hand, the impacts of Scintiglass bear more resemblance to the effects of ERIs in general. This outcome raises critical questions for ATTRACT. Scintiglass was closely aligned with the initial expectations and paradigm of ATTRACT, as it was embedded in the ERI environment. Conversely, OptoGlass3D was only peripherally aligned with the ATTRACT mandate, as it had little or no relation to the ERI environment. The outcome, therefore, is that a project closely aligned with the ATTRACT paradigm was unsuccessful. In contrast, one more marginally aligned with the ATTRACT paradigm was considered sufficiently successful to receive further support.

One tentative lesson to be drawn from this comparison is that consortia, led by industry and embedded in industry cultures and incentives, may be more likely to achieve the kinds of innovation outcomes sought by ATTRACT, particularly market-related impacts such as commercialisation and spin-offs.

Another lesson may be that the effects of the core missions of ERIs are distinct from the impacts that might emerge from commercialisation, the two impact pathways follow very different courses and logic. Understanding whether this conclusion is valid or representative of ATTRACT as a whole would require a larger study and a larger sample of ATTRACT projects.

ATTRACT's effect on network building was also different for the two cases. At Scintiglass, the research was already underway and would have occurred with or without ATTRACT support. ATTRACT funding played a role in resourcing and accelerating the research but otherwise made little difference to its overall progress or direction. However, the OptoGlass3D collaboration became feasible only because of ATTRACT funding – a strongly leveraging effect for the network role of ATTRACT. It is arguable that the cultural and institutional milieux of the two case studies also influenced the emergence of Serendipity. While Scintiglass revealed no substantial Serendipity in its innovation outcomes, OptoGlass3D exhibited Stephanian, network-emergent Serendipity.

ATTRACT's expectations around open innovation are also relevant to our findings. The definition of open innovation in the ATTRACT paradigm is an "open" outcome at around technology readiness level (TRL) 6 or 7, where a number of applications and directions are still possible, and where the outcome is not known beforehand (Chesborough, 2015). This definition is useful in understanding why Scintiglass might be deemed a failure and OptoGlass3D a success. The desired outcome of Scintiglass was clear from the start, namely, a scintillating glass suitable for detectors in high-energy physics. No clearly defined alternative applications were foreseen or emerged during the project's progression. Conversely, OptoGlass3D (and its Phase 2 project, Glass2Mass) envisioned a technique with numerous options for applications, thus aligning well with the ATTRACT objective of open innovation.

REFLECTIONS ON THE SOCIO-ECONOMIC IMPACT

For all three cases, we identified several forms of impact, including aspects of skills development and technological learning, network formation and collaboration, knowledge spillovers, commercialisation, and spin-offs (Figure 4). In spaces led by ERIs, knowledge spillovers were the primary outcome of ATTRACT support. However, commercialisation underpins the largest areas of impact. For OptoGlass3D, the broader social impact is the change brought about by its users via the market. Here, as for ATTRACT, it depends on what the applications will be. This, in turn, highlights the critical role of market impact in the ATTRACT model. For example, applications that accelerate fossil fuel extraction could have negative impacts, while applications in public health or education might have positive impacts. While a focus on commercialisation is appropriate, it needs to be accompanied by attention to the nature of that commercialisation, particularly with respect to the EU's broader policy objectives.

ATTRACT was able to foster Serendipity through the composition of project consortia and the involvement of student projects. However, conclusions about ATTRACT's hypothesis - that Serendipity is a factor in fostering innovation – cannot be made from two case studies. This would require a broader project scope (looking across all the ATTRACT projects) and longitudinal examination (looking at both Phase 1 and Phase 2). However, what the case studies demonstrate is that the analytical framework developed by **CASEIA** has the potential to underpin such studies.

CAPTURING THE DATA REVOLUTION IN RESEARCH INFRASTRUCTURES

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European Research Infrastructures (ERIs) have long played a crucial role in driving scientific and industrial innovation (Wareham et al., 2022), providing essential resources and fostering collaborative environments for groundbreaking discoveries, such as CERN's Large Hadron Collider enabling the discovery of the Higgs boson, the European Southern Observatory revealing the first image of an exoplanet, and the European Synchrotron Radiation Facility's scanning the structure of the ribosome. Traditionally, their contributions have been recognised through advancements in fundamental research and the development of new technologies.

Today, these institutions are increasingly becoming hubs of computational innovation, managing vast datasets and developing sophisticated algorithms that are reshaping how science is conducted (Mayernik et al., 2017, Fabre et al., 2021).

For instance, the European Bioinformatics Institute processes millions of web requests daily, while CERN generates petabytes of data annually through its particle physics experiments. Despite this evolution, conventional frameworks for assessing their impact remain anchored in traditional metrics that fail to capture the full scope of their contribution in the data age.

This chapter explores the transformative impact on open data and computational resources from RIs, using the case study of AlphaFold and its implementation at EMBL-EBI. We examine how these resources are utilised by various industries for innovation, analyse the financial and societal benefits of such open data initiatives, and propose a more comprehensive framework for impact assessment in this rapidly evolving landscape.

INDUSTRIAL UTILIZATION OF PUBLIC DATASETS

Public datasets are now embedded in workflows across industries. The chemical industry regularly consults crystallographic databases for material design (Bruno and Groom, 2014). In the financial sector, open datasets on market trends, economic indicators, and consumer behaviour enable the development of sophisticated algorithms for risk assessment, fraud detection, and algorithmic trading. Furthermore, public datasets on weather patterns, traffic flow, and energy consumption are being utilised by companies in the logistics and energy sectors to optimise resource allocation, improve operational efficiency, and reduce environmental impact (Hossain, Dwivedi and Rana, 2016).

These diverse examples highlight the growing reliance of industry on publicly available datasets to solve complex problems and create value.

The value of public datasets in driving industrial innovation is exemplified in the pharmaceutical industry, where access to vast genomic data and chemical libraries has revolutionised the discovery and development of new medicines (Romasanta, et al., 2023). These resources have enabled everything from target identification to lead optimisation, dramatically reducing the time and cost of bringing new therapeutics to market.

While these established databases have proven invaluable, it was the convergence of public biological data with advanced AI that produced perhaps the most transformative breakthrough in recent years: AlphaFold. AlphaFold, developed by DeepMind in partnership with EMBL-EBI, represents a paradigm shift in protein structure prediction (Jumper et al., 2021). Before AlphaFold, protein structure prediction was a notoriously complex problem. However, the availability of vast, open-access biological datasets—such as protein sequences from UniProt and experimental data from the Protein Data Bank (PDB)—enabled the training of deep learning models that exceeded all previous predictive capabilities.

By integrating these datasets, AlphaFold provided solutions to protein folding challenges that plagued the scientific community for years.

This iterative, cumulative approach to innovation illustrates how public resources can accelerate breakthroughs in fields such as bioinformatics and life sciences. Following the breakthrough, DeepMind and EMBL-EBI collaborated to create the AlphaFold Protein Structure Database, making predicted structures freely available to the global scientific community (Varadi et al., 2022).

DEMOCRATISING ACCESS TO CUTTING-EDGE

Unlike the original AlphaFold breakthrough that required significant computational resources, the AlphaFold Protein Structure Database enables under-resourced academic teams and smaller companies to access high-quality protein structure models (Varadi and Velankar, 2023). While the AlphaFold algorithm is typically used when researchers need to predict structures of novel proteins not present in the database, proteins with specific mutations, or when studying protein-protein interactions. The database is more suitable for smaller research teams that might lack the processing power required to run AlphaFold's algorithm and can instead utilise these pre-computed results for quick lookup of common proteins or for exploring the landscape before diving deep into a particular question.

The COVID-19 pandemic highlighted the transformative potential of AlphaFold and the AlphaFold database in accelerating research on SARS-CoV-2 (Laskowski and Thornton, 2022). Structural biologists made remarkable strides in elucidating structures such as the spike protein, main protease and other key components critical for viral replication and host cell entry. During this period, AlphaFold models provided crucial insights, especially for proteins without experimentally determined structures. The integration of AlphaFold models into various tools, such as the PDBsum web server, allowed for seamless comparisons between computational predictions and experimentally validated data, thereby enhancing the understanding of protein variants and interactions.

This open access has spurred the development of a vibrant ecosystem of derivative tools and resources based on AlphaFold and its database. Projects like OpenFold, ESMFold, and ColabFold exemplify how open data catalyses further innovation, enabling researchers and also companies to adapt and modify AlphaFold for specific applications.

We observed varying approaches to adaptation: some teams with machine learning expertise focused on retraining the algorithm on specialised datasets, while others leveraged the database as a black box prediction tool for preliminary explorations.

By predicting the 3D structure of target proteins involved in human diseases, companies can design drugs more efficiently that interact with these proteins, thereby accelerating the lead discovery and candidate optimisation phases. Some contract research organisations (CROs) have even operationalised AlphaFold in their service portfolios, using it to offer structure prediction as part of their experimental design consultancy. This democratisation has enabled research with proteins beyond traditional pharmaceutical research (Kovalevskiy, Mateos-Garcia and Tunyasuvunakool, 2024).

For example, Agricultural companies use protein structure predictions to develop more effective pesticides and crop enhancement products, food technology companies leverage structural insights to engineer more sustainable meat alternatives, environmental scientists can design enzymes to improve production efficiencies, and materials scientists can develop new bio-inspired materials. AlphaFold has further accelerated progress in synthetic biology, enabling scientists to design new proteins with specific functionalities according to their specifications.

Underlying the broad adoption of protein structure prediction, RIs like EMBL play a vital role in ensuring the accessibility and sustainability of these computational resources (Thakur et al., 2024). These organisations go beyond mere data hosting—they provide essential services including data curation, standardisation, and integration with other biological databases. Through researcher training programs and open data initiatives, RIs foster an environment where scientific information flows freely, enabling recombination and reuse that catalyse new discoveries. This creates a virtuous cycle where innovations feed back into the research infrastructure, advancing both scientific knowledge and collaborative potential.

However, thoroughly assessing the impact of RIs and their tools remains challenging. Especially in the industrial context, corporate stakeholders'

understandable reluctance to share proprietary data and competitive R&D strategies makes comprehensive evaluation difficult (Romasanta et al., 2020).

Consider the economic impact study by EMBL-EBI (Beagrie and Houghton, 2016), which demonstrated a substantial return on investment through metrics such as researcher time savings and increased efficiency. However, its insights were largely limited to academic rather than industrial applications.

IMPACTS OF RI COMPUTATIONAL & DATA RESOURCES

The challenges in measuring commercial adoption highlight a broader question about how we evaluate the impact of scientific infrastructure. While AlphaFold's democratisation has transformed research, traditional impact assessments often fall short of capturing the full spectrum of benefits from open data initiatives. Although economic metrics like ROI and cost-benefit analyses provide valuable insights into financial returns, their limitations especially become apparent when evaluating transformative tools like AlphaFold, the impact of which ripples across multiple dimensions of scientific practice.

Individual Level Impact

At the researcher level, open computational resources fundamentally reshape research capabilities and methodologies. This efficiency gain is particularly crucial for smaller research orga-nisations and companies lacking extensive computational infrastructure, enabling them to compete more effectively with larger entities. By leveraging publicly available tools and data, these smaller groups can now participate in cutting-edge research areas previously inaccessible due to computational constraints. The AlphaFold database exemplifies how open resources transform research, enabling researchers to bypass computationally intensive processes and focus on higher-level scientific questions. Researchers can now rapidly explore speculative or high-risk directions that would have been too resource-intensive even to consider previously. This democratisation of computational tools is not merely accelerating research, it is fundamentally redefining the nature of science.

Researchers are increasingly beginning with computational predictions before moving to empirical validation, inverting the traditional paradigm where computational tools simply support experimental work methods (Terwilliger et al., 2024).

The availability of these open science tools also reduces duplication of efforts across research groups, allowing teams to build upon existing work rather than repeating it. As computational-first approaches become more widely adopted, researchers will increasingly benefit from seamlessly building upon these open resources.

Despite these promising developments, there is a need to assess whether these changes are materialising. Traditional metrics, such as publication counts or citations, fail to capture this qualitative transformation in research capability. Relevant metrics should move beyond simple indicators and embrace areas such as time saved on computational tasks, novel research directions pursued and cross-disciplinary applications.

Resource Level Impact

Computational resources demonstrate unique characteristics that differentiate them from traditional research infrastructure.

Unlike physical equipment, these resources are non-rivalrous - they can be used simultaneously by multiple parties without degradation. Moreover, their value often increases with usage through network effects, as demonstrated by the growing ecosystem of tools built upon the AlphaFold database. The open availability of AlphaFold has triggered sequential waves of innovation: from initial protein structure prediction, researchers developed tools for protein-protein interaction modelling, drug discovery platforms, and mutation impact analysis. Teams have created specialised versions for specific organisms, built comparative analysis tools, and developed interfaces that make the technology accessible to non-experts (e.g. Ahdritz, et al., 2024). This multiplicative effect amplifies the initial investment in public infrastructure, spawning multiple derivative tools, each serving specialised research needs.

Traditional research tools typically have a linear impact path, where usage leads to specific experimental outcomes. In contrast, computational resources can branch into multiple parallel innovation streams, each building upon the core capability in unique ways. Metrics should focus on the dynamic nature of these resources, such as the diversity of users, usage patterns, the number of derivative tools, and integration with other platforms.

Societal Level Impact

The broader implications of open computational resources extend beyond immediate research outcomes, reshaping the innovation landscape (Wareham et al., 2024). These tools empower a more diverse range of participants by providing access to advanced research capabilities, regardless of their institutional affiliations or geographic locations. This democratisation has profound implications for global scientific equity, enabling researchers in resource-limited settings and developing nations to contribute to cutting-edge research, particularly in addressing global challenges (Romasanta and Wareham, 2021).

The transformation extends beyond academic research. Emerging industries like synthetic biology have been built based on these open computational resources. A new generation of startups has emerged that builds its entire business models around these open datasets.

Established companies are restructuring their R&D processes to incorporate these open resources, remaining competitive and attuned to innovations from the outside world. The need for data has driven the emergence of new forms of industry collaboration, with companies increasingly participating in pre-competitive data-sharing consortia and contributing to public databases while maintaining their proprietary applications (Pujol-Priego and Wareham, 2024).

Traditional impact assessment frameworks, which often focus on linear relationships between research inputs and outputs, are inadequate to characterise these complex, interconnected transformations. Measuring societal-level impacts requires capturing the broader ripple effects on product pipelines, the transformation of industry makeup and structures, and the democratisation of scientific discovery.

IMPLICATIONS & CONCLUSIONS

The transformation of research infrastructure in the data age necessitates a fundamental rethinking of how we evaluate, fund, and govern these vital scientific resources.

The failure to accurately capture this broader impact carries significant consequences. The lack of perceived economic return can initiate a cycle that leads to reduced funding and diminished public support, which in turn hinders the development of these resources, ultimately stifling scientific progress and potential societal benefits. Developing more sophisticated evaluation frameworks is therefore essential not only for optimising resource allocation but also for fostering a greater appreciation of the transformative role of open data in scientific advancement. This need for holistic evaluation frameworks is evident in our analysis of AlphaFold and the EMBL-EBI ecosystem. The AlphaFold database serves as a powerful example of how well-maintained data resources can amplify the impact of breakthrough algorithms, demonstrating the multiplicative effects of investing in digital infrastructure.

Building on these insights, research institutions and funding bodies must adopt a more comprehensive approach to infrastructure support. This entails implementing sustainable funding models for data management, establishing metrics that capture usage patterns and derivative innovations, and developing governance frameworks that strike a balance between open access and operational sustainability. Looking ahead, to support data-driven discovery, funding bodies should: establish dedicated budget lines for data infrastructure maintenance, develop performance metrics that capture both direct usage and derivative innovations, and create incentives forprivate-sector contributions to public data resources. The stakes of getting this right could not be higher.

Table 1. Parallel metrics to be considered for data and computational resources

Level	Traditional Metrics	Data/Computational Metrics
Individual	Publication counts, Citation impact, Patents filed, Grants received, H-index	Time saved on computational tasks, Novel research directions enabled, Cross-disciplinary applications
Resource	Usage hours, Number of users, Equipment maintenance costs, Physical access requests,	Derivative tools created, API calls/queries, Integration with other platforms, Data reuse patterns, Network effects
Societal	Economic impact, Jobs created, Patents commercialized, Industry partnerships, Technology transfer	Geographic distribution of users, New business models enabled, Industry structure changes, Open source contributions, Data sharing initiatives

The future of scientific discovery increasingly depends on our ability to maintain and expand these digital commons. As the AlphaFold experience shows, when properly supported, public research infrastructure can catalyse breakthroughs that reshape entire fields and accelerate the pace of innovation across sectors. The challenge now is to ensure our institutions and policies evolve to support this new paradigm of data-driven discovery fully.

THE POWER OF NETWORKS: HOW INNOVATION ECOSYSTEMS FOSTER SOCIAL CAPITAL

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The complexity of how innovation happens today can be daunting, even to those experienced in operating in the space, whether in the public or private sector; the end result of years of research and development in the form of a product, system or service may be the first step in bringing it toward commercialization, a new market and sought after end users. The process of innovation has never been as multifaceted as it is today. The outcomes that organisations and encompassing institutions work toward have become increasingly dependent on external networks that cross industries and disciplines. These networks of stakeholders are created in order to chase novel goals and represent unique network capabilities (Ketonen-Oksi and Valkokari, 2019; Valkokari et al., 2016) and this evolution of how innovation happens has been driven to a significant degree by a shift from a focus on physical resources to knowledge-based resources.

TECHNOLOGY ENABLES A KNOWLEDGE-BASED ECONOMY IN PARTNERSHIPS

Central here is the effectiveness of knowledge creation and transfer toward creating value jointly through interdependent stakeholder relationships (Bridouz and Stoelhorst, 2016). Design, modelling, and prototype testing, for example, have become increasingly prominent as the focus of partnerships due to being technology-mediated, where the emphasis is on the challenges of iteration more than on the hindrances of physical manufacturing that were prominent before the advent of information and computer technology, with its astounding communication and modelling capabilities. The interdependence of mutually beneficial stakeholder relationships is not a new concept. However, the pace of knowledge creation and sharing has increased to such a degree that knowledge has become the currency of many partnerships working toward specialised innovations, with effective communication and proactive participation fueling their progress. Here, the value of partnerships is primarily driven by the shared knowledge that can spark specialised innovations from the research setting to commercialisation.

TOWARD NOVELTY THROUGH SOCIAL CAPITAL IN STAKEHOLDER NETWORKS

These stakeholder networks represent innovation ecosystems, which continue to evolve as traditional boundaries between partners and industries shift. This shift in how ecosystems function and are formed is significantly influenced by organisations and institutions widening their perspectives and methods related to partnerships within their industry and ways of working (Aarikka-Stenroos and Ritala, 2018). The collaboration within these ecosystems can yield valuable novelty also due to broadening the scope of input from stakeholders as stakeholder relationships and connections to potential partners are increasingly at the centre of value-creation efforts (Stam 2015).

Crucial to the success of innovation efforts within stakeholder networks and encompassing ecosystems are various forms of social capital, namely the value embedded in relationships that rely on industry reputation and a proven track record of output (Nahapiet and Ghoshal, 1998). Social capital here represents goodwill on which partner relationships are built that can be leveraged to facilitate needed action (Adler and Kwon, 2002).

It thus plays a significant role in providing access to the required knowledge, resources and potential opportunities in cases where clearly defined transactional payoffs may be absent or delayed (Gedaljovic et al., 2013). Social capital is built on a foundation of social ties that provide access to needed information, resources, and other forms of support (Maak, 2007). Reciprocity is key here, as social capital is cultivated where payoffs are mutually beneficial and go beyond simple transactions that lack a relational element.

These networks represent a web of interconnected actors linked through mutually beneficial ties that derive from social capital benefits. The social ties of these networks can be visualised through social network analysis, such as in the image below.

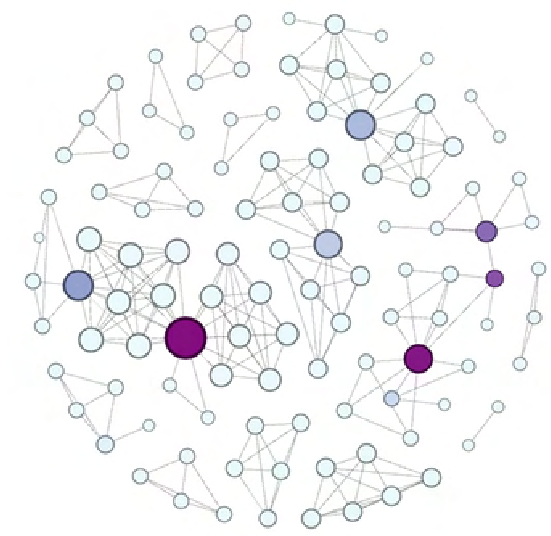

Figure 1. The ATTRACT ecosystem, its projects and social tie structure of the consortium.

The nodes represent members of ATTRACT, and their sizes indicate the number of connections that a node has.

The colours show betweenness centrality, which indicates which nodes are better connected than others. Here, nodes that are involved in multiple consortia have better reach and potential for communication and knowledge sharing for co-innovation, for example.

THE EVOLUTION OF VALUE AND CO-INNOVATION

These relationships, the networks they form and the ecosystems within which they function all revolve around seeking value. What does "value" mean in this particular context? In the past, emphasis was more heavily placed on value that resulted from developing, manufacturing and distributing tangible things (Prahalad and Ramaswamy, 2004). In recent years, a more systemic view of value has been growing; there has been a broadening of the perspective of what constitutes value in an innovation partnership. This has involved adding to traditional perspectives, which focus on more transactional value-from-exchange, where payoffs are well-defined and predictable. Today, broader views on value-in-use, where payoffs are linked to potential owners and uses, and value-in-context, where emphasis is placed on the importance of network relationships in value creation (Vargo & Lusch, 2008), contribute to increasingly diverse determinations of partnership viability.

Here, partnerships among stakeholder networks revolve around actions of co-innovation, where collaboration with both internal and external partners forms the basis of specialised methods and outcomes and, ultimately, value creation. Co-innovation comprises five primary components (Saragih and Tan, 2018). The first and most foundational is collaboration in terms of multi-actor participation in the innovation process. The input from internal and external stakeholders is vital in identifying and leveraging new opportunities and insights, such as those with customers, businesses, universities, or suppliers.

Collaboration allows for a beneficial blurring of the boundaries between partners.
Second, coordination is needed to direct attention and action toward shared methods and goals among contributing stakeholders with diverse inputs. Third, convergence allows for the focus to be placed on specific goals in terms of, for example,

technology, organisational ways of working or institutional outcome expectations once coordination has created a general shared direction.

Fourth, complementarity is needed to incorporate resources and capabilities effectively in terms of technology management, organisational culture, and behaviour management, as well as formal institutional governance issues.

Here, organisational and institutional capabilities can be sources of unique added value in contrast to more typical technologically based capabilities or resources. Finally, co-creation is vital to the process of co-innovation. Seeking out new abilities and motivations to implement solutions through collaboration with internal and primarily external stakeholders is indispensable here, for example, when it comes to methodology, iteration and user testing decisions. These collaborative methods, built on efficient and effective communication and ways of working, can be leveraged to attract external stakeholders with whom to create innovative outcomes that would be otherwise impossible to achieve in-house.

DIVERSE AGENCY AMONG PARTNERS

As co-innovation is adopted by those seeking to leverage broader stakeholder partnerships, it enables stakeholder agency, or the ability to influence desired outcomes, in new ways. This agency is socially embedded among those participating in goal-oriented actions. The agency of partners enables the leveraging of social capital in the network, where trust, collective methods, and shared norms help facilitate mutually beneficial advancements, resource management, and benchmarking, for example (Nordstrom and Steier, 2015).

Foundational to enabling agency among stakeholder partnerships is clarity in expectations regarding benchmarking and capabilities. The bonding and bridging social phenomena that strengthen these instrumental social ties, enabling stakeholder agency, are built on reciprocity and the co-creation of value in the diverse forms mentioned earlier.

As such, innovation is a continuous process with a complex interplay among diverse ecosystem actors, characterised by overlapping methods and desired outcomes (Zhao, 2023). Here, complex connections are formed based on shared meanings that are socially constructed through the process of innovation and the selection of stakeholders with whom to collaborate (Dattee et al., 2018). Notably, innovation is not simply the effective leveraging of valuable ideas within a clearly defined group of actors; instead, its potential is expanded when co-innovation among diverse actors yields outcomes based on unique perspectives, fostering a collaborative effort and interdependent synergy (Rajala et al., 2016).

These network dynamics are complex and affected by the characteristics of stakeholders. We can again visualise the ATTRACT network, which exemplifies network diversity in terms of size, background, and type of organisation.

In Figure 2, the red/yellow map shows public and private actors within the consortium (red private, yellow public, orange mixed). In contrast, the blue map shows the size of the entity as an indicator of size (light blues are start-ups, blues are SMEs, and dark blues are large companies/multinational organisations).

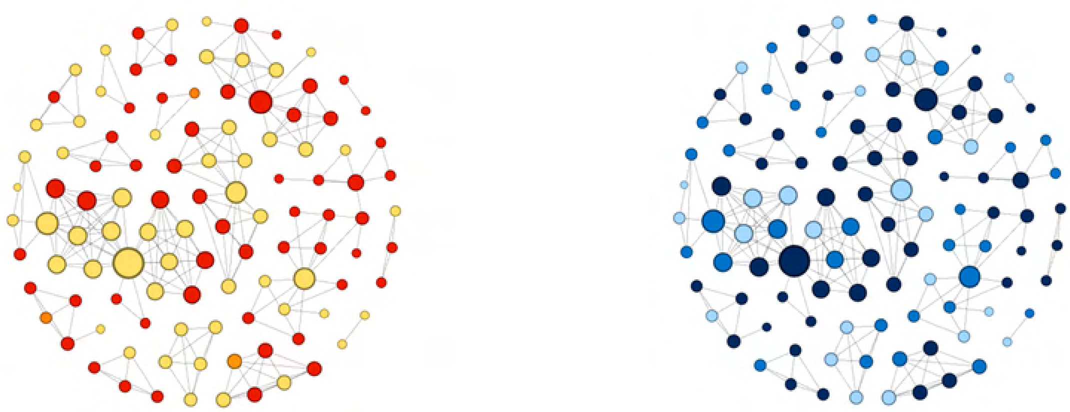

Figure 2. The ATTRACT ecosystem, its projects and social tie structure of the consortium.

CO-INNOVATION ECOSYSTEMS & RESEARCH INFRASTRUCTURES

These themes of innovation, stakeholder partnerships, wider networks and ecosystems within which they operate to collaborate toward novel outcomes represent the building blocks of a co-innovation ecosystem, which can be defined as dynamic co-productive environments for research, development and innovation collaborations where stakeholder activities are highly interdependent and where there is a co-creation of value perspectives between industry and research participants (Schroth and Häußermann, 2018).

Here, characteristics of exploration and knowledge adoption across stakeholder perspectives are motivated by interdisciplinary knowledge sharing, a fundamental currency of these partnerships (Kelonen-Oksi and Valkokari, 2019).

Furthermore, RIs work to build bridges between co-innovation groups and more institutional intergovernmental or national research infrastructures in order to create better and leverage needed international collaborations in responding to challenging problems that require diverse input from highly specialised actors who might not otherwise be connected to such infrastructures at scale.

Here, there is a highlighting of co-innovation opportunities for industry actors who are less aware of the competitive advantages that may lie in the advanced technologies being developed outside the marketplace.

The Research Infrastructures (RIs) of ATTRACT (European Commission, 2019) align with this concept of a co-innovation ecosystem, as they serve as spaces that provide resources for research, enabling innovation while fostering partnerships between education and public services to benefit from potential outcomes.

The components of co-innovation ecosystems can be enhanced by research infrastructures, which emphasise reducing the fragmentation of research among ecosystem participants. This is achieved by increasing collaborative efficiency through the avoidance of effort duplication and coordinating the optimal framing of potential uses of these infrastructures across diverse networks.

The ATTRACT ecosystem is a particularly interesting example of a dynamic and evolving co-innovation ecosystem where the benefits from research and commercialisation connections are formed throughout the project. Visualising this below, the black ties represent the existing relationships between actors as they form the consortia. The green edges are central here as we draw to a close, as they indicate the research relationships that are now established, through which network density has grown significantly and distant clusters have been connected to one another. This is a striking visualisation of the power of networks, social capital and innovation, so well represented in the case of ATTRACT.

DIVERSITY AND INCLUSION IN ENGINEERING

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While engineers have an immersive and important impact on technological, business and societal development via their research and innovation, they are often diversity-blind. Engineers overlooking potential end-users with diverse backgrounds affected by their research and innovation processes and outcomes are the rule rather than the exception. In engineering, more often than not, men build a world for men (C.C. Perez, 2019).

The problem, however, goes well beyond differences in sex and gender. As a case in point, Seaborn, Barbareschi, and Chandra (2023, p. 1) found "… evidence of limited, obscured, and possible misrepresentation in participant sampling and reporting along key axes of diversity: sex and gender, race and ethnicity, age, sexuality and family configuration, disability, body type, ideology, and domain expertise" in human-robot interactions.

In this short book chapter, we reflect on opportunities and challenges in making engineering projects more responsible by overcoming their diversity-blindness, even beyond sex and gender. We achieve this by providing information on the relatively sparse theoretical background in this matter and on our empirical data and methodology. Based on this, we highlight the opportunities and challenges of leveraging human diversity for technological and business success and discuss whether diverse teams contribute to this. We conclude the paper by discussing our findings in the light of their technological and business impact.

THEORETICAL BACKGROUND

While national governments and the European Commission have made genuine efforts to address the diversity-blindness in engineering, the focus of their initiatives has been limited to sex and gender, and their general uptake has been disappointing.

Funding agencies in various countries and the European Union have requested the sex- and gender-responsiveness of scientific research and innovation (Hunt et al., 2022; European Commission, 2020). Despite the incentives provided in the European Commission's Horizon 2020 funding programme, engineers did not systematically apply a sex- and gender-inclusive approach to their projects (Cheveigné et al., 2017).

There is some literature suggesting that engineers can make their research and innovation outcomes sex and gender-responsive by modifying their research and innovation processes or by diversifying their teams. To adapt their research and innovation processes, engineers considering the diversity of human beings must critically reflect on and likely modify their research questions and methods, as

well as their reporting of results and innovation activities (Nielsen et al., 2018; Werker, 2021). Engineers could use existing examples (Tannenbaum et al., 2019) and adapt existing guidelines for gendered research and innovation (Nielsen et al., 2018) to consider diversity beyond sex and gender in their research and innovation processes.

The social categories beyond sex and gender are age, race, disability, sexual orientation, social class and others (Rice et al., 2019).

Moreover, intersectionality, i.e. people being under-privileged because of a combination of social categories as mentioned before (Rice et al., 2019), might also play a role in research and innovation processes.

To alter their teams, engineers can use diverse team members with various values, perspectives and ideas. Nielsen et al. (2018), suggest a positive relationship between diversity in research teams and more inclusive research and innovation outcomes. Yet, to our knowledge, there is no empirical evidence supporting this positive relationship.

DATA & METHODOLOGY

The data we analyse stems from the eighteen ATTRACT Phase 2 research projects funded by the European Commission's Horizon Europe funding scheme. The ATTRACT project has been taking place in two phases, i.e. the already finished ATTRACT Phase 1 and ATTRACT Phase 2, running until August 2024.

The aim of ATTRACT was to identify and develop breakthrough detection and imaging technologies. Therefore, it spans basic research, applied research and market innovation, thereby aiming at both technological and business success. In ATTRACT Phase 1, 170 project teams received €100,000 each to develop a proof of concept for their technology (ATTRACT, 2023a). In ATTRACT Phase 2, eighteen research projects, often emerging from a few ATTRACT 1 projects, received €1,000,000 in funding to convert their proof of concepts into market-ready prototypes while also seeking private funding and industry collaborations to launch their prototypes into the market (ATTRACT, 2023b).

We rely on two types of data, i.e. semi-structured interviews and a survey. For the first type of data, we carried out the semi-structured interviews via MS Teams in three steps. In the first step, we interviewed all project leaders and eleven team members of five teams in early 2023. We followed up with the team leaders of these five teams in autumn 2023 in a second step. In the final third, we conducted interviews with the team leaders of the remaining thirteen research projects in the winter of 2023 and 2024. For the second type of data, we carried out a survey in June 2024, which was mainly completed by team leaders.

Here, we employ a mixed-methods approach, sharing insights from both types of data. Leech and Onwuegbuzie (2007) provide a typology using three criteria: (1) emphasis on approaches, (2) time orientation, and (3) level of mixing.

Regarding (1), qualitative and quantitative data have roughly equal status in our reflection.

Regarding (2), to learn from the interviews, we carried them out sequentially with the survey.

Regarding (3), our level of mixing is relatively high as we follow up on questions about diversity in research and teams in the semi-structured interviews, with related and adapted questions about the same topics in the survey provided us with more comparable data.

Secondly, based on what we learned during the interviews, we adapted the questions in between steps and developed the questions for the survey based on our learnings in the interviews, thereby entering the interviews by using flexible data collection methods that allow us to take advantage of emerging topics and concepts as suggested by Eisenhardt, 1989.

Below, you will find a reflection on our descriptive results from the survey, along with some insights from the interviews. While we intentionally use results from the within-case analysis of the interviews, we also conduct a comprehensive cross-case analysis and report findings from individual cases. Cross-case analysis presents the challenge that the emerging theory is often parsimonious, as it excludes all aspects not replicated across multiple cases (Eisenhardt and Graebner, 2007). Here, however, we are looking for opportunities and challenges of diversity in research and in teams in engineering.

In this context, singular results are also of interest, as they help us identify openings for business and technological opportunities.

REFLECTION

Due to the requirements of ATTRACT Phase 2, we find universities, research organisations and firms engaged in project teams collaborating on an international level. At the same time, the diversity of project team leaders and members is rather low. All research team leaders have a background in either engineering or natural sciences, sometimes combined with a business or entrepreneurial background.

Most of the team members we interviewed are researchers and innovators. One of the team leaders is a woman. The female team members typically work on the business or legal aspects of the projects.

None of the project teams had considered the diversity of human beings in their research and innovation processes when we first interviewed them. Yet the interviews worked as a sort of intervention. In particular, the project leaders were very interested in the question of diversity in research and innovation processes. In ATTRACT Phase 2, project leaders were expected to develop prototypes and secure funding for their market introduction. They were therefore seeking business opportunities for the technological solutions they were developing.

Two out of the five project leaders we interviewed in the first round incorporated our suggestions on how to consider the diversity of human beings into their plans. In the second round of interviews, six months later, they reported concrete prototype changes, such as a surgical device also available for the smaller hands of female surgeons and an optical solution providing visibility for colour-blind men.

Initially, the diversity of team members did not play a role at all in considering the diversity of human beings in the research and innovation processes, most likely because the majority of the engineers carrying out research and innovation had a somewhat similar background regarding gender, age and educational background. In the case of the surgical device, the project leader enlisted female surgeons to help him develop a prototype suitable for smaller female hands, which would also likely be useful for men with smaller hands.

In the survey conducted after all interviews were completed, we found that ten out of eighteen research teams considered the diversity of human beings. Often, they considered various types of diversity. In Figure 1, you can see the distribution of the kinds of diversity considered, with age, gender, and educational background leading.

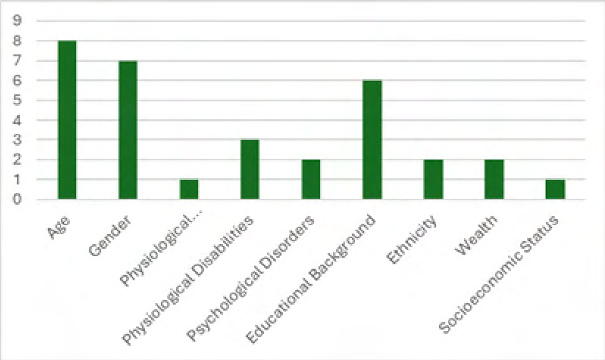

Figure 1. Types of diversity considered

In the survey, it also became clear that the phase in which the diversity of human beings was considered was rather late in the process, i.e. mainly in the development phase (see Figure 2).

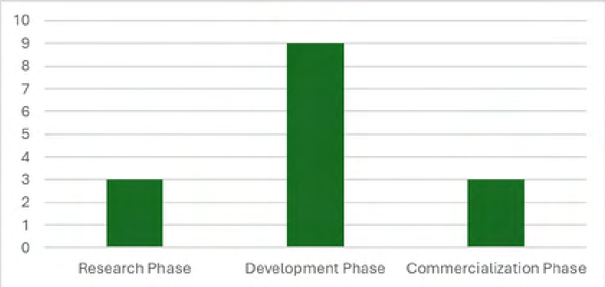

Figure 2. Phase of diversity considered

While project leaders saw the business opportunities of taking diversity of human beings on board, they also had to deal with severe challenges:

Entrepreneurially experienced leaders had to convince their younger, academically oriented colleagues and their business partners of the business value of inclusive engineering. While this approach seemed to work well with the project members, business partners turned out to be a significant challenge: Several project leaders reported that, although in principle, their industry partners were very interested, they wanted to see the prototype before investing more money. However, building the prototype is expensive. Finding partners who are willing to fund prototypes up-front is a serious challenge for the project leaders.

CONCLUSIONS

While none of the eighteen project teams had considered the diversity of human beings in their research before our interviews, ten did so afterwards (see Figure 3). Team diversity did not initially play a role, but it was addressed in the context of more inclusive developments.

The ATTRACT Phase 2 research projects had a particular history and set-up. We conducted our data collection and analysis while they were developing their prototypes and seeking funding.

Our findings suggest that diversity-blindness in engineering does not occur because of a lack of willingness but rather a lack of knowledge of how to approach diversity in their research and teams.

To overcome diversity-blindness in engineering, several things had to come together: Firstly, the project leaders needed information about how to consider the diversity of human beings in research and innovation processes. Without originally intending to, we did so with our interviews. Secondly, they needed entrepreneurial experienced leadership to convince team members and partners of the business value of their technological developments.

This points at another important role for entrepreneurial leadership on top of the already shown roles in these breakthrough technologies (Feenstra, Hopp, Pruschak and Werker, 2024). Lastly, they needed time and money to build prototypes adhering to the needs of diverse human beings when relevant. In overcoming diversity-blindness in engineering, project leaders would not only open new markets but also provide more inclusive engineering solutions for human beings otherwise underserved.

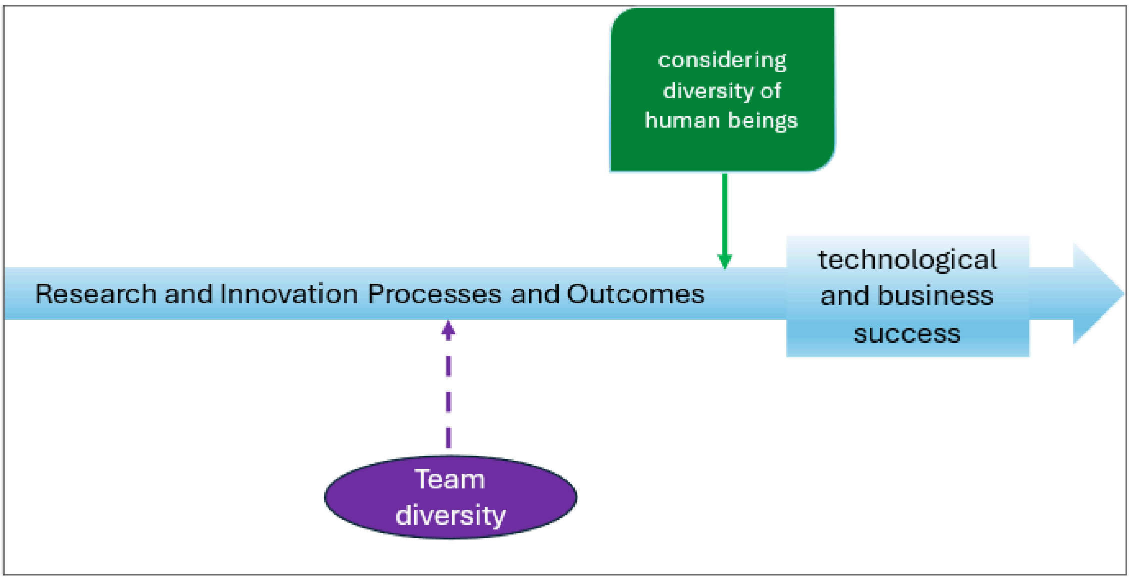

Figure 3. Diversity in research and innovation and in teams as driver of technological and business success

ERIS AND NEW CONCEPTUALISATIONS OF FINANCIAL, POLITICAL, & SOCIAL COSTS AND BENEFITS

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A BRIEF INTRODUCTION TO THE CONVENTIONAL ECONOMIC-MULTIPLIERS' WAY OF THINKING FOR ERIS

Approximately two-thirds of the EU's economic growth is attributed to research and innovation. European Research Infrastructures (ERI) are fundamental to this progress. They play a crucial role in advancing knowledge and technologies, enhancing the efficacy, efficiency and effectiveness of research, and contributing to the overall development of the ERI Ecosystem.

The European Strategy Forum on Research Infrastructures (ESFRI) emphasises in its ESFRI White Paper (2020) that investments in research infrastructure (RI) are strategic investments for enhancing Europe's capacity to support innovation, technological advances, and global competitiveness. This contributes to the long-term sustainability of European quality of life and the development of solutions to global challenges. The link between research, innovation, and RI is multifaceted and complex, with no universal approach. The timeframe between a breakthrough in fundamental research and its practical implementation varies and is challenging to foresee.

The ERI ecosystem is encountering challenges that require revised strategic regulations. To address this, Europe needs more apparent prioritisation, improved coordination, and more efficient use of ERIs.

Although the field of policy and strategy has progressed significantly in the past decade regarding ERIs, differences in national research and innovation systems result in varied approaches to road mapping and funding RIs. Despite this diversity, as emphasised in ESFRI (2020), it is important to consider the establishment of specific joint strategies to enhance the overall effectiveness of the RI policy. It is essential to regularly update inventories of existing RIs and identify needs and gaps to maintain the relevance and effectiveness of the policy as it adapts to the evolving research landscape. Transparency in prioritising national needs while considering European perspectives is crucial to ensure a fair and balanced approach, aligning national priorities with broader European research goals.

Improved coordination of RI road mapping processes within national research and innovation ecosystems, as well as outreach to other relevant national policies, is necessary. Prioritisation of new and existing RIs should be done based on available funding for RIs. Coordination structures for RIs should be established at the ministry level and support coherence between national and ERI processes.

OPTIMISING INVESTMENTS: STRATEGIES FOR EFFECTIVE RESEARCH FUNDING

What factors influence the success of public investments in research and technology?

Public investments in research and technology have long-term goals and require significant intellectual and financial commitments.

These investments involve frequent risks, limitations, and benefits that may not always be immediately tangible, and the results are not always successful (Nagesh and Thomas, 2015).

Although many factors influence the success of public investments in research and technology, they have not been extensively studied in recent years. Specifically, there has been limited research focused on identifying the contextual factors that contribute to the success of public investments carried out by academic and research organisations.

To prepare strategies for adequate research funding, it is necessary to consider the results of relevant empirical research on factors influencing the success of public investments in research and technology, legal frameworks (at the EU level), and state-of-the-art (in the EU).

Van der Panne et al. (2003) reviewed 43 studies on the factors determining the success and failure of innovation. They categorised them into four groups related to firm, product, project, and market. Additionally, Smith et al. (2008) identified nine key factors that impact organisations' ability to innovate, namely management style, leadership, resources, organisational structure, corporate strategy, technology, knowledge management, employees, and innovation process. Based on these factors, a relationship model of factors influencing the management of innovation was proposed.

Ginevičius and Vaitkunaite (2016) identified twelve organisational culture dimensions that significantly impact performance: involvement, cooperation, information transmission, learning, client care, adaptability, strategic direction, reward and incentive systems, control systems, communication, agreement, coordination, and integration.

Ginevičius et al. (2008) emphasise the influence of state aid in various sectors and identify key success factors. Their analysis of state subsidies to enterprises confirms that state aid has a significant influence on production, research, experiments, and educational projects. They found that the intensity of assistance has the most influence – the higher the intensity of the aid, the greater the effect. Educational projects had the best investment-to-impact ratios, followed by research, experimental, and production projects. In comparison, aid to enterprises providing services was found to be the least effective.

Ambroziak (2016) examines the impact of state aid on research, development, and innovation (R&D&I) and its influence on competitiveness. The author discusses theoretical arguments for intervening to support research and development activities, legal framework and eligibility criteria for state aid for R&D&I, and the significance of public assistance for R&D&I in EU Member States. The analysis of legal changes in the conditions for granting assistance for R&D&I confirms that such aid contributes to improved economic competitiveness and the EU industry. However, like any government intervention, state aid should be targeted towards enterprises with genuine development potential and provided only in cases of market failures.

Wendland (2015) provides an insightful analysis of the modification's scope and the new concepts introduced by the European Commission, including R&D&I state aid rules, modernisation, and enforcement effective from 2014. Conversely, Buts (2019) highlights stakeholders' concerns regarding the ambiguity of state aid rules on R&D&I and the resultant negative impact on innovation.

To address these concerns, an exploratory case study and participatory action research were conducted as part of the **ExSACT** project to identify and rectify ambiguities in the R&D&I rules. While the rules are generally comprehensive, we identified three crucial areas of ambiguity: non-economic activities, the pricing calculation of goods or services provided by research organisations, and ancillary activities of research organisations concerning the 20% threshold.

In the **ExSACT** project, we discussed what constitutes a 'safe' interpretation of the concepts involved for each category. The **ExSACT** project investigated how state aid regulations influence the financing of research, research and technology infrastructure (RI/TI) usage, and intellectual property rights (IPR) transfer in the EU.

Findings indicate that limited awareness of state aid rules can hinder public investment and complicate RI/TI usage and IPR management. While organisations recognise the importance of IPR, they need more support from licensing and inventor incentives. Intellectual Property (IP) registration processes are most refined for inventions and trade secrets, with less emphasis on industrial design and trademarks.

The research in the **ExSACT** project highlights the need to simplify state aid rules and improve understanding within state administrations. This would enable smoother cooperation and technology transfer between the ERI, industry stakeholders, and society.

How can regulations be navigated to maximise the impact of investments?

As emphasised by the Council, the European Economic and Social Committee, and the Committee of the Regions, research and innovation as sources of renewed growth require customised strategies to fit the specific characteristics of each Member State. Consequently, defining, planning, and implementing these strategies, which are necessary to enhance the quality of investment in research and innovation, present a significant challenge for all Member States.

Several Member States are currently implementing reforms related to public support for research and innovation. It has been observed that implementing such reforms aimed at improving spending quality and ensuring economic and social impact poses a continuous and long-term challenge for all countries. To enhance the value for money, it is important to maximise the impact of research and innovation policies, which can be achieved by establishing stronger connections between quality and the resources allocated to these areas. It is essential to have focused incentives to improve the quality of public spending and sustain growth by investing in research and innovation.

Research and innovation influence many policy areas and involve many actors. Therefore, they should be based on an integrated strategy and managed at a sufficiently high level of politics.

Such a strategy should cover research and innovation activities, including investment in infrastructure. The policy should be guided by a stable multiannual strategic framework and public investment planning, considering the long-term impact of research and innovation. This is already encouraged by the Council Directive 2011/85/EU of 8 November 2011 on the requirements for budgetary frameworks of the Member States, which, among other things, outlines the features and benefits of credible medium-term fiscal frameworks. Including growth-enhancing spending, such as investment in research and innovation, in the multi-annual planning of the medium-term budgetary framework can combine the benefits of more stable public finances with a higher visibility of the medium-term priorities of governments. It can provide greater credibility and increase the attractiveness of the research and innovation system.

Public investments in research and innovation are managed mainly through programmes whose objectives are traditionally set in terms of scientific disciplines, technological fields, or industrial sectors. While addressing citizens' concerns, Member States should consider allocating more attention to programs that tackle critical societal challenges, as there is significant potential for growth in transforming these into future business opportunities. Better coordination of priorities between Member States, based on joint planning of national research and innovation agendas, increases the impact of public investment in a given area of research and innovation.

In all Member States, a substantial portion of public funding for research and innovation is in the form of institutional funding for universities, research institutes, and other public research and research organisations. These institutions should be encouraged to be entrepreneurial and seek new opportunities and partnerships outside Europe. The urgency of this action lies in the need for improved knowledge transfer to the private sector, which can only be achieved by redirecting resources towards activities that have the most significant impact.

INNOVATING FOR SUCCESS: ENHANCING SCIENCE COMMERCIALISATION THROUGH EXPERIMENTATION

Sara García Arteagoitia, Rob Fuller
Innovation Growth Lab

The journey from scientific discovery to commercial success is fraught with uncertainty. Despite numerous scientific breakthroughs, translating these innovations into marketable products and services often encounters significant obstacles. Efforts to promote commercialisation and foster university–business collaboration have grown, yet these initiatives frequently face challenges such as misaligned goals, cultural differences, and limited resources. Navigating the complex landscape of intellectual property, funding, and regulatory requirements further complicates the path from lab to market.

As a result, many promising scientific discoveries struggle to achieve their full commercial potential.

The **NEXT** project sought to change this by promoting the use of policy experiments to test approaches to overcoming the challenges in science commercialisation. In the course of this project, the Innovation Growth Lab (IGL), working in collaboration with researchers from the Barcelona School of Economics, Nesta, and ESADE, developed a handbook that explores the challenges in this area and outlines proposals for experiments that could address them. Concurrently, IGL established the University-Industry Impact Accelerator, where three project teams working to advance science commercialisation at various organisations received training on experimentation and were guided through the process of designing experiments to address specific challenges they faced.

However, our understanding of the factors driving successful commercialisation is limited. In recent years, scholars in the innovation field have made significant efforts to improve our understanding of the challenges and enablers of science commercialisation, typically using qualitative case studies or observational data (Battaglia et al., 2021; Fini et al., 2020; Organisation for Economic Cooperation and Development, 2019). Despite these efforts, our understanding of the effectiveness of the different types of tech transfer activities undertaken by research institutions is still limited.

In this chapter, we introduce the concept of experimentation and explore its application in advancing the commercialisation of science. The first section describes experimentation and highlights its value as a policy tool. The second section discusses how experimentation can provide insights at various stages of commercialisation support interventions, from programme design to implementation. The third section addresses common barriers to running policy experiments and offers strategies for overcoming these challenges.

THE POWER OF EXPERIMENTATION

We define ‘experimentation’ as the use of a structured approach to learning from the implementation of a policy or programme. This involves setting out specific questions that stakeholders wish to examine and putting in place systems that will generate evidence addressing those questions.

Taking an experimental approach to programme development means testing programmes initially at a small scale, ensuring that processes are put in place to learn from the implementation and using the insights generated to improve the design or implementation as the initiative is scaled up. New programmes or policy initiatives often fail to have the expected impact because of relatively minor design or implementation problems that are only encountered when the initiative is launched. Taking a gradual, iterative approach instead ensures that these mistakes are made and lessons are learned while piloting at a small scale when only low levels of resources have been committed.

Once any initial implementation difficulties have been ironed out and the intervention is being delivered as expected, a more formal evaluation method can be used to investigate whether the intervention has the desired impacts or to optimise those impacts to improve its effectiveness over time.

Using an approach like this enables organisations to reduce the risk of delivery failure and failure to achieve the expected results, implying significant savings in time and resources that would otherwise be devoted to an impactful programme.

The experimental ideal, however, is to randomly assign units – whether individual people, businesses, research groups, or other entities involved in the program- to different forms of the intervention or, sometimes, to a control group that does not receive any intervention at all. Random assignment makes it unlikely that there are any systematic differences between the groups and ensures that those assigned to various forms of intervention are similar on average, both in terms of obvious, observable characteristics (such as gender, age, and qualifications) and more subtle, unobservable traits (such as motivations, experience of entrepreneurship, attitudes to risk, and so on).

This implies that, as long as the sample size is sufficiently large, any differences in outcomes between the groups can be confidently attributed to the interventions being tested.

Given that the experimental method is fundamental to progress in many areas of science, it is perhaps surprising that randomised experiments have only occasionally been applied to science commercialisation. Experiments have been carried out to investigate how to increase researchers’ engagement in commercialisation efforts (Sormani et al., 2022) or whether innovation vouchers can promote collaborations between businesses and external knowledge providers (Bakhshi et al., 2015; Balabay et al., 2019; Cornet et al., 2006; Kleine et al., 2020).

However, given the rapid growth in recent years of the use of randomised experiments in other areas of innovation policy and public policy more generally (OpenAlex, n.d.), there is clearly much potential for randomised experiments to improve the effectiveness of interventions at the university–business interface.

PATHWAYS TO EXPERIMENTATION

There are several points at which a programme or initiative aimed at supporting science commercialisation may benefit from incorporating experimentation into its development.

An experimental approach can be used to explore the assumptions on which a programme is based. For example, the successful implementation of a programme may rely critically on assumptions about the willingness of the target group – whether researchers, businesses, or others – to participate and might need to be validated before rolling out a large-scale intervention.

An illustration of this comes from one of the projects developed in the University–Industry Impact Accelerator, which involved providing training to academic researchers on knowledge exchange. In the course of a pilot that involved offering the training at three universities, the number of researchers who signed up for the training was lower than had been expected. This led the project team to refocus their efforts on how to encourage fellow researchers to participate in the training before running a randomised experiment to test its impact.

Experimentation may also be used to test the mechanisms through which an intervention is expected to take effect. For example, it can be used to probe the motivation of potential participants and test how to induce a bigger response from them

Such randomised experiments will often involve comparing alternative forms of messaging for outreach efforts – for example, testing whether researchers are more likely to respond to messages that emphasise the potential benefits to their own careers or to wider societal benefits when encouraging them to sign up for a programme to engage with businesses (akin to Ganguli, 2021).

Alternatively, organisations may have already developed a programme and wish to test whether it is leading to the intended results. The most straightforward approach to this is to compare the participants to a control group who have not – or not yet – had the opportunity to participate in the programme (as in the innovation voucher experiments: Bakhshi et al., 2015; Balabay et al., 2019; Cornet et al., 2006; Kleine et al., 2020). However, for larger programmes with several components, the potential for learning from experiments like this may be limited.

Figure 1. Key Issue Matrix from "Experimenting in University-Industry Collaboration: An Innovation Growth Lab Ideas Handbook"

An all-or-nothing comparison will not provide any insight into the relative contribution of the different components of the programme towards the impact achieved, and, if the results are disappointing, it cannot be known which of the activities should be strengthened. For this reason, one approach sometimes taken in other fields is to combine an experimental evaluation of the overall impact with a comparison of differences in the type of support or the depth of support provided (e.g. Anderson & McKenzie, 2022; Dalton et al., 2021).

Often, the key motivation is not so much to test the overall impact of a programme but rather to optimise its effectiveness. For example, in the context of a training programme, those involved in implementation may have questions about the correct type of content, the best format for interactions, or the length of the programme. A particular question that has increasingly arisen in recent years is how the effectiveness of training delivered online compares to that delivered in person – an important consideration, given that making events available online often means that a wider range and larger number of participants can be reached at substantially lower cost.

Another of the projects supported under the University–Industry Impact Accelerator serves to illustrate how experimentation can be used to optimise a programme. A research institute had developed an integrated proof-of-concept programme of funding, training and mentoring for researchers to support them with the commercialisation of specific technologies they had developed. As a new initiative, it was clear that small-scale piloting was essential before being gradually scaled up over the coming years.

However, the limited number of eligible technologies also meant that carrying out a randomised evaluation of the overall programme would not be feasible in the near future.

Instead, the implementers decided to test approaches to reaching out to potential private-sector partners, something that was expected to be a particular pain point.

The institute, therefore, designed an experiment in which potential partners are randomly allocated either to be approached by the researcher themselves or by a technology transfer officer from the lab. Tracking the number of responses from businesses and the number of initial meetings secured will allow the organisation to assess which of these approaches should be used when the programme is scaled up.

Finally, it is possible that the design of the programme is clear, and the implementers are confident that it has the expected impact. However, the challenge lies in making potential participants aware. For example, it may be that the target group are difficult to reach or has only limited time or bandwidth to devote to exploring new initiatives – something that is true of both many academic researchers and many small businesses.

If so, experimentation can be used to optimise outreach efforts or improve conversion rates from initial expressions of interest to committed participation.

The third experiment, designed under the Accelerator, dealt with the issue of outreach optimisation: it involved encouraging STEM graduates to sign up to participate in a traineeship programme that would give them experience working within big science organisations such as CERN. As a new initiative within an already well-established general traineeship programme, one of the key concerns for the national innovation agency was that students would not learn about the opportunity through their existing networks and – even if they heard about them – would not feel they understood enough to invest in making an application. The agency, therefore, decided to test whether investing more efforts to reach out to and discuss the opportunity with students would result in a higher rate of applications from qualified candidates.

The experimental design involved giving final-year students in randomly selected engineering and physics courses the opportunity to participate in a webinar about the traineeship programme, comparing them against students in the other courses who received information only through email.

OVERCOMING CHALLENGES IN EXPERIMENTATION

Implementing a randomised experiment is not always a straightforward process, and there are often hurdles that need to be overcome to put one in place. However, these barriers are often less significant than might be imagined. Some of the common challenges in implementing policy experiments include sample size, outcome definition and measurement, data collection and research ethics.

Any quantitative analysis of the outcomes of an experiment requires a sufficient sample size, whether of researchers or businesses reached by the interventions. The sample required depends on many factors (not least, the size of impact that the experimenter would like to be able to detect) but is typically in the dozens or hundreds. If the programme or initiative is not being implemented at this scale, then it is unlikely that a randomised experiment or another quantitative analysis method will generate meaningful results.

Nevertheless, there may still be potential for experimenting with particular elements of the programme, such as the research lab above, which turned its proof-of-concept programme evaluation into an outreach optimisation experiment.

Quantitative analysis is also only possible if it is clear what the expected outcomes of an intervention are and if data can be collected on these outcomes. Setting up an experiment typically requires dedicating some time at the design stage to thinking through the expected outcomes, often by drawing up a 'theory of change' or a diagram of the channels through which the intervention is expected to act.

It is not necessary for there to be a complete consensus about which of the outcomes is the most important or most likely, since multiple outcomes can be monitored. However, the implementers need to broadly agree on how to conceptualise the outcomes.

Once agreed upon, the desired outcomes have to be turned into numerical measures that are amenable to quantitative analysis.

This is increasingly becoming less of a barrier, given the continued adoption of machine learning methods that enable quantitative measures to be derived from textual or other types of qualitative data. In many experiments, a bigger question is about how to ensure that participants in the experiment provide the data needed for analysis.

Once the outcomes have been identified, collecting data can present several challenges in itself. Rates of response to surveys are often very low, particularly when addressed to busy audiences such as academics or businesses. However, it is often possible to find alternatives to survey data that can be used to assess the outcomes of an intervention.

One approach is to use data generated in the course of delivering the intervention – for example, tracking whether participants have completed an online training programme, or using their responses to quiz questions built into the interface. Another option that is increasingly being employed is the use of public data sources (such as patent filings) or to generate data from information a business or researcher posts to their website or social media accounts.

Finally, an important question sometimes raised in setting up an experiment – particularly one involving a control group that will not receive support – is about the fairness of excluding participants from interventions that are intended to have positive effects.

When it is clear that an individual or a business would benefit from the intervention being tested, this certainly becomes a concern. But implementing organisations often face budgetary or capacity constraints that mean they cannot include all the eligible participants in their programmes.

In these cases it may be inevitable that some of those who have the potential to benefit from participation do not have the opportunity; if so, including a random element in the selection is less controversial.

More commonly, however, it is not known how well an intervention works or whether it leads to the desired outcomes at all. In this case, there is no ex ante reason to believe that individuals would be advantaged or disadvantaged from being allocated either to participate or to a control group.

Given how little is known about effective ways to promote university–industry collaboration, this leaves many types of intervention open to experimentation.

CONCLUSION

There is still much to learn about how to improve the effectiveness of science commercialisation efforts. The existing examples of experimentation in this field – including the three designed as part of the University–Industry Impact Accelerator – show that experimentation is feasible and beneficial to tackle those challenges. And while designing and executing experiments may not always be straightforward and requires upfront planning, much can be transferred from experiences in other areas of innovation policy (Edovald & Firpo, 2016).

As organisations and individuals increasingly engage in experimentation, they will become more adept and confident in its application. Even preliminary experiments with smaller, less critical aspects of a programme can provide significant learning opportunities to the programme and organisation, and help scale programmes up successfully. Embracing experimentation as a continuous process encourages ongoing improvement and adaptation, leading to progressively better commercialisation outcomes.

HOW DOES ENTREPRENEURSHIP EDUCATION FACILITATE KNOWLEDGE CIRCULATION?

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Upscaling innovation stemming from academic research necessitates navigating through the 'valley of death' - a critical phase that requires time to validate the technology's operationalisation and meet market expectations (Barr et al., 2009; Randolph Beard et al., 2009). This journey is especially demanding due to the long-time horizon of scientific research and the inherent technological and market uncertainties (Maine, 2014).

Recent studies indicate that the failure rate for technology-driven ventures in this phase can exceed 90%, highlighting that significant technological, financial, and collaborative risks are involved in commercialisation (Engel et al., 2014; Romme & Holmström, 2023).

Universities are no longer just institutions of learning and research. Instead, they are considered engines of technical development tasked with developing scientists with best practices and skills (Blankesteijn et al., 2018; Fayolle & Gailly, 2015; Klofsten & Jones-Evans, 2000). One of the key elements of this function of universities is entrepreneurship.

Entrepreneurship as a socio-economic phenomenon is driven by three important factors, namely the existence of opportunities, the process of discovering opportunities (opportunity identification) and the decision to exploit such instances (Shane & Venkataraman, 2000; Szulczewska-Remi & Nowak-Mizgalska, 2023).

To foster the awareness of upscaling opportunities for science and technological innovation, science and technology universities provide an important platform through entrepreneurship education (Rasmussen & Borch, 2010; Wilson et al., 2007).

Universities have created governance structures to foster entrepreneurship and entrepreneurship education. A key example is the establishment of technology transfer offices, which play a crucial role in providing entrepreneurship training opportunities, thus nurturing a generation of entrepreneurially minded researchers (Vincent, 2022).

Additional initiatives include incubators, legal support for intellectual property, mentorship for young student-entrepreneurs, and dedicated educational programs focused on entrepreneurship in science (Blankesteijn et al., 2021; Good et al., 2019).

Between these elements, knowledge needs to circulate to learn and profit from each other's entrepreneurial experience. Knowledge circulation is an important component of this process. Knowledge circulation occurs when working alongside each other as functional teams and when external stakeholders, such as industry partners and potential customers, are engaged.

It includes generation, dissemination and application of knowledge to drive innovation and economic development (Blankesteijn et al., 2018). A process that involves not only the transfer of knowledge through formal channels like academic publications and patents but also through tacit knowledge shared when researchers, entrepreneurs and industry partners interact (Etzkowitz & Leydesdorff, 2000; Hayter et al., 2021).

As the spin-off company readies for the commercial market, exchanges with joint ventures, external companies and industry partners add to the growing list of agents.

Developing entrepreneurial competence is considered a transversal skill by entrepreneurship scholars, prompting individuals to engage in personal and social skill development, as well as learn how to apply critical and problem-solving skills. Entrepreneurship Education, thus, is multifaceted, encompassing multiple human dimensions such as emotional, cognitive, behavioural and social. Moreover, the entrepreneurial learning literature acknowledges entrepreneurial learning as a situational process that builds on both direct and indirect experiences of individuals and the collective team (Nogueira, 2019).

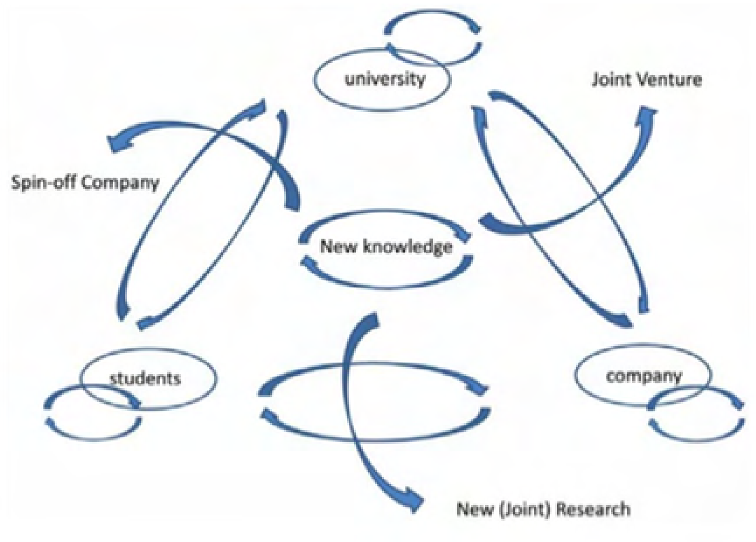

Figure 1. Blankesteijn, M., Sijde, P. van der, Sam, C. (2017). Entrepreneurial Universities and Knowledge Circulation. In: Smart Specialization strategies and the role of Entrepreneurial Universities (2017); ed. by Caseiro, N & Santos, D. p. 81-98

Effective knowledge circulation ensures that scientific findings are not confined to academic settings but can be translated into practical applications that benefit society. Knowledge circulation (fig. 1) illustrates processes and emphasises the dynamic interplay between agents in academic research, industry collaboration, industry partners and entrepreneurial initiatives (Blankesteijn et al., 2018). When spin-offs develop innovations, the university's technology transfer office is often encountered as a means for patenting. Here, new knowledge is generated and exchanged between the researchers, the spin-out company, and the university.

HOW DOES ENTREPRENEURSHIP EDUCATION FACILITATE THE CIRCULATION OF KNOWLEDGE?

The **NEXT-GEN-TECH-ED** research provides valuable insights by examining the European Horizon 2020 funded program, ATTRACT, and the R&D&I project teams currently in the Phase 2 cohort. Our research highlights the progression of scientific teams through technology readiness levels 4 to 7.

By doing so, we offer a practical perspective on 1. how entrepreneurial knowledge is shared among the diverse partners involved in a process of knowledge circulation and 2. how entrepreneurship education facilitates this knowledge circulation during these phases of technology development.

Our study employs a mixed-methods approach, combining quantitative and qualitative methods, to provide a comprehensive overview of the entrepreneurial development of scientists in this unique cohort.

RESULTS

KNOWLEDGE CIRCULATION

TRL4: Technology validated in the laboratory

Team 10 leveraged the role of external partnerships and complementary skills to validate their technology. They faced technical challenges and slowed the pace of commercialisation down. "So, we are pursuing...Several things and this project isn't the only project that is supporting this research I should add". This indicates ongoing validation and development efforts within the laboratory environment.

TRL5: Technology validated in a relevant environment

Team 1 collaborated with industry partners, leveraging their environment and collaboration for testing. Adjusting their project goals based on feedback and lessons learnt through iterative engagement," we realised talking with industries that...some objectives that were more 2nd order we should have put them like first order and vice versa," indicating the need to better align project goals with industry needs.

Team 3 pursued multiple commercialisation paths while engaging with collaboration partners, leading to flexibility in application areas.

Explaining that "both the components individually and the system can have different commercialisation paths because the components can have several applications", which expands the team's industry and consortium partnerships for experiments and validation.

Team 14 benefited from academic collaboration, gaining support in various areas such as workshop space for business operations, finding investment and access to resources or lab expertise. Stating how "this project really helped in setting up some of the collaborations because it ties us very tightly to academia", providing the flexibility to act on unexpected findings or to exploit resources.

TRL6: Technology demonstrated in a relevant environment

Team 5 engaged early with the market, through industrial fair participation and leveraging consortium partners, resulting in early sales, but faced regulatory and resource allocation challenges. Confirming that "So we have three products, and we are developing one. There's more finished and ready to go. We indeed even sold two pieces of it. So, this is fine."

Team 15's collaboration and flexibility when collaborating with a range of partners introduced market pressure and uncertainties. Evident in statements such as "Sometimes you end up feeling paralysed, not being able to do anything because you don't know what the least wrong thing is to do."

Team 13 built a collaborative network which included academic institutions, industrial partners and end-users. In addition, the team prioritised the practical application of their research, which ensured that the solution developed addressed real-world relevance. Emphasising how time was taken to find a balance between complexity and practicality, "But on the other side, also very practical aspects... instead of using one week..." to ensure real-world applicability.

Team 4 developed a custom value chain to expedite progress towards industry showcases and validation of the technology in a relevant environment. With the team acknowledging what's missing by stating:

"...we have to make the value chain and for that we have started with the suppliers, the raw material suppliers..." to allow their product to reach the desired market.

TRL7: System prototype is operating in a relevant environment

Team 8 focused on integration and long-term sustainability, employed adaptive strategies and concentrated on testing and development of the solution. Explicitly mentioning "At least some part of that project is at TRL 7, meaning that we're offering it on our website".

At an initial stage, knowledge circulation occurs within the laboratory or testing facilities and through a smart selection of partners with complementary skills. This process allowed teams to engage in iterative testing, underscoring the importance of collaborative engagement. Knowledge circulation becomes more pronounced among partners in TRL5 when aligned project goals facilitate the exchange of practical insights and resources to meet market expectations.

Later, at more mature technology readiness levels (TRL7), scientists demonstrate the ability to implement contingency plans as emerging issues arise and apply critical thinking to problems, which enables confidence in facing market acceptance.

ENTREPRENEURSHIP EDUCATION (EE)

TRL5: Technology validated in a relevant environment

Team 2 integrated technical and commercial skills, highlighting the need for effective communication between team members "application engineers or system integrators [are] people that will be able to understand how the technology works, and we'll be able to explain it to the external world" as a need for moving through the different levels.

Team 9's market understanding allowed proactive strategies to pivot their approaches based on market needs and technological advancements. Indicating "I was thinking what else can we do with this technology? And I was exposed to this... different direction..in working in pathology".

Team 7 followed a causal approach involving meticulous planning and adherence to schedules, faced ecosystem bureaucracy, administrative processes and limited interaction. "I am a project manager, so I plan in general, so I don't embark if I don't plan because I like to follow schedules and deliverables because I think it's this is a professional way to do".

TRL6: Technology demonstrated in a relevant environment

Team 6's early collaborative feasibility study with potential customers and gradual focus on the production stage confirmed their technology readiness. "So together with a customer, and that is actually something that worked here as well, where we basically sit together". This provided many opportunities and new challenges, such as stakeholder coordination and motivation, team adaptation, and balancing technical and commercial development.

TRL7: System prototype is operating in a relevant environment

Team 12 engaged in collaborative commercialisation and market–centred initiatives with industry partners. This team included key partners, such as business consultants, who bridged the gaps between the division of labour between scientific research and commercialisation. Highlighting "So we decided to move on to phase two, and basically we split the task of like developing the project...

I took care of collecting ideas and partners for the scientific field, and he was doing the more...Market and commercialisation part", but mentioning the awareness of limited resources and difficulties in resource allocation.

Entrepreneurship education serves as a mediator for knowledge circulation in this ecosystem, equipping scientists with essential skills for commercialisation. Teams integrate knowledge gained vicariously into their processes and benefit from the integration of technical and commercial skills.

The competence to select the right labour division becomes crucial to explaining complex technology to external audiences across all technology levels. Additionally, we evidence that knowledge which circulates collaboratively between partners enhances the science teams' market understanding and their adaptability to create proactive environments which enable the exploration into new directions for scientific innovation.

CONCLUSION

Smart partner selection and effective division of labour, which includes leveraging complementary skills, play a crucial role in validating the technology, providing testing facilities, and offering additional business operational support. This approach enables the development of custom value chains for science teams. As scientists advance to higher technology readiness levels, they begin to implement contingency plans to address emerging issues. They apply critical thinking to problems and make proactive decisions, allowing them to adapt to market needs and expectations.

Combining technical and commercial skills allows for multiple commercialisation paths to emerge and for various applications of the technology to be realised. For example, one team used this approach to first determine the feasibility of their innovation and then gradually focus on production and development.

Entrepreneurship education becomes an effective tool for knowledge circulation by equipping scientists and researchers with essential skills for commercialisation. Entrepreneurship educators, students and the science-business ecosystem can benefit from knowledge circulation. By teaching students how to develop networking and collaboration skills, educators can foster environments where entrepreneurial knowledge circulates effectively with the contribution of diverse actors.

With the inclusion of actors such as universities, industry partners, and entrepreneurial support organisations, science-based entrepreneurship educators can develop programs aligned to real-world practices.

This approach identifies principles which build critical skills in partnership development, develop know-how in leveraging complementary resources and increase the introduction of effectual thinking patterns into science-based entrepreneurship programs.

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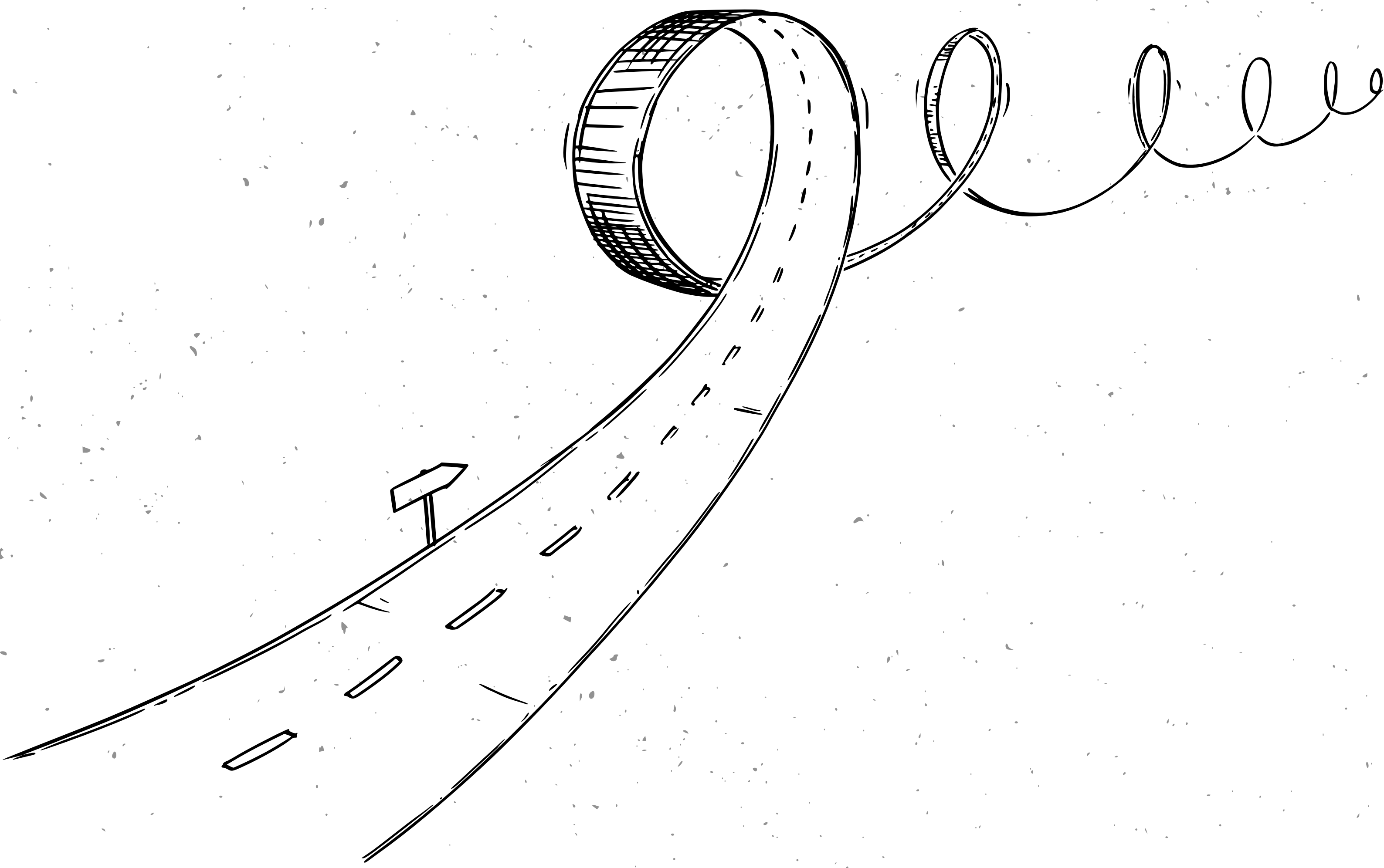

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