SCIENCEPRENEURSHIP

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Science, Entrepreneurship and Sustainable Economic Growth

BY

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INVESTOR IN PEOPLE

To Lucia, who sought a beacon of light in a lacklustre world,
and Arianna, who helps me to find a path through the labyrinth
of the mind.

The real voyage of discovery consists not in seeking new landscapes,
but in having new eyes.

Marcel Proust, *La Captive*;
Vol. 5 of *Remembrance of Things Past*.

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ABOUT THE AUTHOR

Professor **Piero Formica** began his career as an economist at the OECD's Economic Prospects Division in Paris. In the second half of the 1970s, with a group of economists from Cambridge under the guidance of Professors Nicholas Kaldor and Wynne Godley, he worked on European and regional economic policies. The 1980s and 1990s saw him involved in the European programmes for the birth and development of incubators and science and technology parks. Formica collaborated with the European Business Network – a network of around 140 quality-certified EU BICs (Business and Innovation Centres) and 100 other organisations supporting the development and growth of innovative entrepreneurs, start-ups and SMEs – and for a decade (1995–2006) he was a member of the Scientific Committee of the International Association of Science Parks. As an expert advisor to the European Commission's Directorate-General responsible for the programmes mentioned above, he was part of international teams to design incubators and science and technology parks (STP) in the UK, Italy, France, Spain, Portugal, the Netherlands, Germany and Finland. Outside Europe, Formica carried out similar activities in Australia, China, Canada, Argentina, Brazil and Canada.

Professor Formica is the Founder of the International Entrepreneurship Academy Network. He was a Professor of Economics with a particular focus on innovation and entrepreneurship at the Jönköping International Business School, Jönköping University, in Sweden. Since 2010, he has been a Senior Research Fellow of the Innovation Value Institute at Maynooth University in Ireland. He leads an international research team on experimentation and simulation of high-expectation start-ups. At the C_LAB in Veneto, born out of the collaboration between the Universities of Padua and Verona (C_LAB is a transdisciplinary laboratory for the development of innovation projects between the universities and businesses), Piero Formica in the role of professor and mentor conducts experiments for the development of innovative projects by students who attend the Lab.

Professor Formica has received several awards and honours:

- The Innovation Luminary Award in June 2017 from the Open Innovation Science and Policy Group under the aegis of the European Union 'for his work on modern innovation policy'.
- Honorary Professor bestowed by the University of Mar del Plata (Argentina) and the University of Tehran, Faculty of Entrepreneurship.
- Senior Research Fellow of the Enterprise Research and Development Centre of the Business School at the University of Central England in Birmingham.
- Visiting Professor of Knowledge Economics and Entrepreneurship at the Jean Monnet Faculty of Political Studies at the Second University of Naples, Italy.
- Guest Professor at King Saud University (Saudi Arabia) and the Curtin University of Technology, Curtin Business School (Perth, WA).
- Special International Professor of Knowledge Economics and Entrepreneurship at Beijing University of Aeronautics and Astronautics (China).
- International Professor (Marie Curie project) at the Faculty of Economics and Business Administration, University of Tartu (Estonia).
- International Professor of Knowledge Economics and Entrepreneurship at the Higher Colleges of Technology, United Arab Emirates.
- Member of the Advisory Council of the Institute for Enterprise and Innovation at the University of Nottingham, and the Board of Governors of the University of Bologna, Italy, where he held the Professorship of the Economics of Innovation in the Master programmes' 'Business Law' and 'Technology Management'.
- Advisor at The Cambridge Learning Gateway (Cambridge, UK).
- Councillor of the World Certification Institute.

Professor Formica serves on the Editorial Boards of Industry and Higher Education; the *International Journal of the Knowledge Economy*; the *International Journal of Social Ecology and Sustainable Development*; the *Journal of Global Entrepreneurship Research*; the *South Asian Journal of Management*; and *Frontiers in Education*. He writes for the digital edition of the *Harvard Business Review*.

Professor Formica has published extensively in knowledge economics, entrepreneurship and innovation. His most recent published works include: *The Experimental Nature of New Venture Creation: Capitalising on Open Innovation 2.0*, Springer, 2013; *Stories of Innovation for the Millennial Generation: The Lynceus Long View*, Palgrave Macmillan, 2013; *The Role of Creative Ignorance: Portraits of Path Finders and Path Creators*, Palgrave Macmillan, 2015; *Grand Transformation Towards an Entrepreneurial Economy: Exploring the Void*, Emerald Group Publishing, 2015; *Entrepreneurial Renaissance: Cities Striving Towards an Era of Renaissance and Revival*, Springer, 2017; *Exploring the Culture of Open Innovation: Towards an Altruistic Model of Economy*, Emerald Publishing Group, 2018; *Il Bazar delle Follie: Pensieri sull'Italia nell'età della conoscenza*, DuePuntoZero di Ad Maiora Editoria, 2018; *Parole e Voci dell'Innovazione: Per una Cultura del Cambiamento*, il Mulino, 2019; *Innovation and the Arts: The Value of Humanities Studies for Business*, Emerald Publishing Group, 2020; *Econaissance: The Reimagined School and the Culture of Entrepreneurialism*, Emerald Publishing Group, 2020; *Nature's Voice: Health and Humanities*, bioGraph, Chicago, 2020; *La Voce della Natura: Cultura della salute e cultura umanistica*, bioGraph, Chicago, 2021; *IDEATORS: Their Words and Voices*, Emerald Publishing Group, 2022.

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FOREWORD

SCIENCEPRENEURSHIP: THE HISTORICAL PERSPECTIVES

The reader may find this a difficult word – not easy to articulate. And I am not sure how it will translate beyond English. Very interested to see the German interpretation! But because it is unusual, and you will not find it in the dictionary perhaps your curiosity will stimulate you to read on – beyond the title. Words are a law unto the interpretation of the reader. Here we have two – Science and Entrepreneurship. Translating the terms into human form Piero in his imaginative exploration invites us to consider scientists and entrepreneurs and their creative and practical work and the marriage of two enormously important areas of human activity, endeavour and achievement. The journey you will take as you travel through the pages of this book may open your mind to realisations of how amazing progress in human knowledge and achievements have depended more on the way people of different cultures, disciplines, backgrounds and knowledge have found ways to identify common ground where knowledge of disparate kinds finds synergistic, even symbiotic connectivity, than the originality and significance of the discovery or new knowledge. The core question to have in mind as you read on might be 'How does knowledge including scientific knowledge become translated into action and substance – tangible and applicable "stuff" that saves lives or helps make them more meaningful?'

And yet history has interesting lessons for us – and none I know is more interested in historical perspectives than Piero. I want to explore as part of your preliminaries as readers some of the past thinking on these momentous issues – we are not the first to consider them. I do not wish to be pedantic by quoting dictionary definitions of the words that make up the author's title – SCIENCEPRENEURSHIP. But readers do need a perspective and a context to tackle the examination of the validity of this new word – Sciencepreneurship.

Starting with Science and Scientists we have much wisdom from ancient times and ancient cultures. But I prefer to recall a time of great discovery and thinking when the word *Scientist* was first used. And in doing so I make

no apology for bringing to your notice a great unsung hero of science and its practical application. And I suggest, in his own way he was also an entrepreneur. William Whewell FRS was a polymath. He was Master of Trinity College Cambridge from 1841 to 1866. His two seminal works 'History of the Inductive Science from the earliest to the Present' and 'The Inductive Sciences, Founded upon their History' began a new era in the philosophy of science. Before Whewell, the word 'scientist' did not exist. Isaac Newton who was also Master at Trinity Cambridge, and earlier generations of world changing scientific changemakers were known as Social Philosophers. A wonderful term. Even in those days, the role and position of science in the greater order of things was considered in the round and not in isolation. Pathfinders and changemakers such as Whewell, hardly ever remembered today, were the historical forerunners of the champions of today who advocate and act to dismember barriers between functions, faculties, sectors, cultures, nations and peoples. Just to fill in a bit more about William Whewell – and his amazing abilities as a nineteenth century entrepreneur indeed. His record shows that not only did he coin the term *scientist*, but also *physicist* and suggested to Michael Faraday the terms electrode, ion, dielectric, anode and cathode. Whewell would have been in his element today in centres of innovative excellence to see the way in which scientific specialties and innovative technology platforms have converged and become joined up and connected with the entrepreneurial spirit that seeks always to make positive change happen and through newfound human capabilities to relate and cross boundaries and barriers to enable the development of new products and processes to benefit mankind and save lives in ways not previously seen.

I began discussing words and how we interpret them, and we have explored the words 'Science and Scientist'. And Piero's work enables us to examine in detail how science and scientists may be drawn into a world of greater coherence and significance through entrepreneurship. But what is entrepreneurship? I am concerned it is often considered in a far too limited way – with the accent on 'starting companies and making money'. For me, entrepreneurship is a state of mind. A province to be occupied by ALL who would see positive change happen. I associate it with another key word of our century – Innovation. Dictionary definitions of entrepreneurs, entrepreneurship and the entrepreneurial mindset are boring and unimaginative – for example, Chambers twentieth Century dictionary – '*one who undertakes an enterprise: a contractor or employer: and organiser of musical or other entertainments*'. My experience of the entrepreneurial mindset is entirely different and in no way limited to business situations. When asked 'what is an entrepreneur' I prefer to tell the story of a great writer and social philosopher, George

Bernard Shaw who, trapped one day in his London house by a much younger man firing a succession of arcane questions at him. The great man reached a point of great frustration, it is said, and rose angrily to stop the questioner in his tracks with words to the effect – '*Shut up young man! You look at things and ask WHY? But I dream of things that never were and ask WHY NOT*' My experience is that *Why Not people* change the world. Pathfinders and changemakers and constructive disrupters rarely have easy lives. And they are often surrounded by those with the negative mindset based on '*Yes but…*' thinking.

Throughout Piero's narrative do look carefully at the compelling arguments supporting the importance of transdisciplinarity. He also embraces Open Innovation and analysis of the key importance of the convergence of technologies, made ever more possible through advances in digital communications technology. The internet and the worldwide web have indeed contributed to human capabilities to connect and join-up in ways not previously possible. And if connecting leads to action not simply knowledge sharing, we can observe the phenomenon of '*connectricity*'. Another new word for consideration – connectedness plus energy. You will also find in these pages further reason to contemplate the theme often explored by the author in his writing of *Creative Ignorance*. When truly open minds with complimentary and mutually challenging content and experience come together things not thought of before can emerge. 'Dreaming of things that never were' as did George Bernard Shaw is part of the practice of Sciencepreneurship. It has been encouraging in my recent experience in Cambridge and other European centres to engage with the work of an organisation named Innovation Forum which has for some years now organised events and activities focussed in the life science areas where the expression 'Entrepreneuring Science' has been widely used. Parallel thinking with Piero and his associates. New thinking now permeating the processes of education and practice.

As a life scientist and one who has spent a lifetime in and around medicine, healthcare, and health services, I am pleased to conclude this introduction to Sciencepreneurship with a wonderful example of the processes at work in very recent times. The Covid pandemic has devasted our world and there has been untold suffering and disruption. But consider the amazing speed with which vaccines effective in bringing an end to the severity of the pandemic and saving millions of lives were developed in months – whereas previously years would have been required. The depth of scientific knowledge including latest developments in genetics and genomics worldwide was brought together across borders and barriers and industrial R&D and production expertise connected, again across borders. Open Innovation prevailed and the

entrepreneurial spirit enabled *connectivity and connectricity* to join up people and knowledge and optimise the prospect of success. This example and the narrative which follows this introduction should cause us all to think very deeply about the underlying issue of great importance – human behaviour and human relationships. Neither knowledge, great scientific ideas nor imagination are sufficient to bring positive change and disruption. Relational aspects of human activity make the real difference.

Alan Barrell

PROLOGUE

A NEW RENAISSANCE HERALDED BY THE SCIENTIFIC ENTERPRISE

> *Scientific entrepreneurship is the science of freedom from ill-being, breaking down the barriers between human health, that of other living species and nature.*

'I think, I act and therefore I construct' is the hallmark of scientists who promote entrepreneurship and sometimes are new venture creators. As the various forms of art, science can surprise people and stimulate fantasies and passions within them. In science, as in art, imaginative minds draw models that must adopt a second nature to have a practical effect. This second nature is the attitude to entrepreneurship.

At the dawn of the Renaissance, artists and scientists began the work of dismantling everything for centuries taken for granted. In 1482, and for the next 15 years, Milan stood on the shoulders of Leonardo da Vinci (1452–1519), the universal genius at the service of Ludovico il Moro (1452–1508). As the art historian Giorgio Vasari (1511–1574) put it, Leonardo was a ≪truly admirable painter, sculptor, art theorist, musician, writer, mechanical engineer, architect, scenographer, master metal worker, artillery expert, inventor, scientist≫. Leonardo not only gave Milan and its surroundings an artistic identity, but he also helped to mark the transition from the feudal to the capitalist mode of production. Thus, a new era began in Milan and its surroundings, introducing the profile of what would become the modern manufacturing entrepreneur.

The second half of the eighteenth century witnessed scientists mainly engaged in the study of gases and electricity. Even before common sense, they were guided by an enthusiasm that endangered, for example, Benjamin Franklin's (1706–1790) life when he flew a kite in an electrical storm, writes Bill Bryson. Today, one encounters scientists whose discoveries fuel

the entrepreneurial process around things and events that are fundamental to life on Earth. What is more, scientists themselves wear entrepreneurial clothes, and entrepreneurs contribute to the scientific process.

In the early days of the industrial revolution, Giovanni Aldini (1762–1834), a scientist from the University of Bologna and nephew of the physicist Luigi Galvani, renowned for the discovery of animal electricity, visited together with the economist Luigi Valeriani (1758–1828), professor at the same university, the new technical and professional schools in France, Great Britain, Germany and Belgium, learning the best practice of the new technical education and training on offer in Europe. The fruit of their travel was first the gestation and then the foundation of a technical school. A self-sustained trend of new firm formation resulted from a cross-fertilisation process between in-company learning-by-doing training and formal education at the technical school for new mechanical qualifications. The encounter between the scientist and the economist and their intellectual nomadism led to the regeneration of the preindustrial revolution experience in promoting the link between education and entrepreneurship as an essential condition of development in the wool and silk textile manufacturing, whereby Bologna was at that time renowned in Europe. The entrepreneurial spill-overs of the actions pursued by the entrepreneur-scientist show a long queue. We have to wait until the 1920s for the birth in Bologna of the packaging machinery industry – today, a world-leading industrial cluster.

Throughout nearly a century and a half, the Bengali renaissance was an innovative milieu of social and religious reformers, giants of letters and scientists such as Jagadish Chandra Bose (1858–1937), among the pioneers of research in radio technology, and Satyendra Nath Bose (1894–1974), best known for his work on quantum mechanics in the early 1920s. They tilled the territory on which tech start-ups were seeded and grew and now enrich the digital economy landscape.

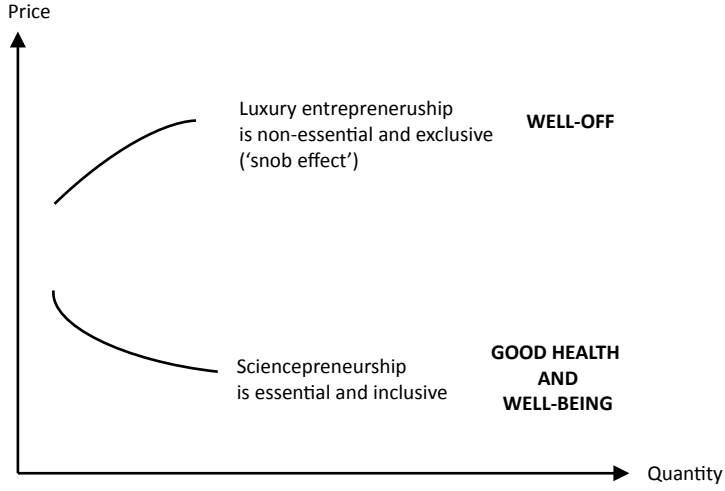
Science and scientific entrepreneurship: a gradual double revolution. The oxymoron is only apparent. The gradualism of the revolution depends on hastening slowly, that is, on the readiness of action combined with the slowness of careful reflection. The gradualism is also due to the non-coincidence between the time the revolution breaks out and the time of the ordinary people's perception and understanding of it. It was the case with the 'scientific revolution', roughly between the mid-sixteenth to the end of the eighteenth century. As with the emergence of classical mechanics and the chemical revolution, the unfolding quantum revolution opens up a vast

horizon of possibilities for scientific entrepreneurship. The changes it brings are protracted processes, and how they unfold over time depends on the cultural traits of the social community involved. These include the characters of the educational and research institutions that play a crucial role in the knowledge economy. The community at the University of Stuttgart runs a podcast called Made in Science. It features scientists, alumnae and alumni, employees and students from that University. ≪The conversations are not only about the interviewee's current work, they also focus on their personality, what inspired them, and their career. One thing that all of the guests have in common is that they have studied or worked at the University of Stuttgart, or are still doing so, i.e. they are 'Made in Science'. How did they become who they are? Looking back, what would they do differently?≫. Made in Science is the outcome of the scientific and entrepreneurial communities' co-evolution in a long-term process. Its strength lies in discovering things hidden beneath the standard knowledge maps. The Greek philosopher Parmenides (fifth century BC) argued, 'Nothing comes from nothing', and prior experience is the source of understanding how to depart from it. Intuition and foresight make today's most advanced knowledge obsolete, opening up spaces to draw new maps. These, once consulted, give free rein to businesses, products and services that would otherwise be inconceivable as being at odds with common sense by uncovering surprising elements and unexpected juxtapositions.

Made in Science embodies the science of human nature that aroused Adam Smith's (1723–1790) interest, as David Hume (1711–1776) pointed out. Within this science lies the transformation of capitalism. Mercantilist capitalism gave way to Keynesianism, which, in turn, was replaced by neoliberal capitalism. Today, having to redress sharp and growing wealth inequalities in the face of political, social and natural upheavals, the search for new entrepreneurial behaviour turns against neoliberalism. Made in Science challenges the established knowledge system that considers the market an end in itself. Activist capitalism comes to the fore, which adopts ethical criteria. Its fundamental missions are to combat the inequalities of predatory capitalism and to do what is suitable for the planet, conserving and protecting wild nature. This is, for example, what Patagonia aims to do by producing high-end outdoor clothing and investing in companies founded by scientists to help solve the environmental crisis. The Californian company has sold 98 per cent of its capital, relinquishing voting rights, to the non-profit Holdfast Collective, which is to deploy the profits not reinvested in the company for environmental initiatives. The remaining two per cent is

allocated to the Patagonia Purpose Trust, made up of scientists and experts in the green economy.

With the increasing concentration of power and wealth, predatory capitalism causes the 'Made in' to slide towards the 'Made in Luxury', socialising with Mr Snob as depicted by the Norwegian-American economist and sociologist Thorstein Bunde Veblen (1857–1929). Snobs are gratified by owning material goods that represent a status symbol: in fact, they reject anything that is not exclusively for the wealthy few. They love conspicuous consumption, purchasing at sufficiently high prices – their demand is directly proportional to price, rather than inversely – to ensure the luxury and exclusivity of what they buy. With rising costs, they ostentatiously display prestigious properties, luxury cars, yachts, works of art, precious carpets and what else. On the contrary, engaged in solving complex problems originating from multiple causes that are hard to interpret, Made in Science is invaluable and inclusive. The price of a vaccine or a good with a climate-protecting environmental certificate so high as to exclude the majority from buying it would aggravate an ongoing epidemic and the greenhouse effect, respectively. It would also jeopardise the well-being of those with such a well-having state. Deeply embedded in Made in Science is the concept of a common good all together we must protect.



Made in Science versus Made in Luxury

One does not recognise at first glance the scientists and entrepreneurs who prefer to solve entirely new problems and do not beat the roads marked by the detailed knowledge maps available. They prefer to discover avenues that do not exist on those maps. In the health field, scientists and scientific entrepreneurs combine their skills to bypass impassable frontiers according to available maps. They do so by being open-minded to information gaps and accepting the uncertainty managed by the exercise of intelligence as to whether their explorations in unknown research lands will work or not. It is the case, for example, with the reinvention of cancer treatment, reported by the *Financial Times* on 14 August 2022. Animal experimentation gives way to an innovative technology replicating a miniature human tumour in a dish: a tumoroid. Thus, innovative therapies based on human genes and cells or even customised for patients are being used that might not work at all on animals.

Starting from what is known about the world and driven by creative drives and passions, scientists and scientific entrepreneurs formulate thoughts translated into actions that do not automatically lead to social progress. For this to happen, the scientific enterprises that arise from their thinking and acting should be shaped to bring progress to society as a whole. The civilisation of machines first and the technological-digital development later, and the enterprises in their wake, have ended up distributing the benefits, both social and economic, unevenly throughout society, extracting more and more value from the workers but less and less for their benefit.

The scientific enterprise is not a machine built according to the industrial model established in the successive ages of industrialisation. Having reached maturity, that model moulded a routine value creation based on the performance metric of efficiency and incremental improvements of 'what we have always done'. In short, work has been done by digging into the soil of previous experience and, thus, relying on links with the past. The catastrophic risks threatening humanity and the planet ask for enterprises that leverage scientific discoveries to achieve radical innovations. In doing so, they tear up the cultural roots of the new always built on the old proper of ancient Greece.

The scientific enterprise has the shape of a tree growing in all directions under the impetus exerted by the intersecting forces of science and entrepreneurship. Its model envisages explosive value creation based on deep literacy of new effective ways of thinking and working at the intersection of science and entrepreneurship, thus fostering new offerings for collective well-being.

THE UPSIDE-DOWN SCIENCEPRENEURSHIP TREE

The fruits of the scientific enterprise tree are counter-intuitive possibilities.

The tree is upside down to give light to its roots featuring the culture of the sciencepreneurship.

The figures of the scientific thinker, the business creator, the organiser of science and entrepreneurial activity, and the persuader of the goodness of initiative stand out in one or more persons. Growing expectations foreshadow university scientists – lecturers, post-docs, or graduate students – intentionally engaging in academic entrepreneurship to commercialise technologies derived from university research. Their entrepreneurial identity, the 'who am I?', is comparable to that of the Flemish innovator and influential cartographer, cosmographer Gerardus Mercator (1512–1594), who depicted the 'outside' world – that world beyond typical experience – which had been precluded from view before him, thus paving the way for long-distance trade. The entrepreneurial scientist unveils another external world whose landscape is dotted with paths along which scientific discoveries run towards the entrepreneurship that translates them into achievements for the collective well-being. Ways of producing, working and, indefinitely, the living are changing. In turn, a new world opens up for the academic entrepreneur who has to learn how much effort starting a company requires, primarily to launch and conduct pilot experiments for problem-solving. Market research involves a scientific approach to generating hypotheses about who might want the product and

testing whether they want it. This research can be faster-paced and more goal-oriented than academic studies, and it may be necessary to change gears quickly. In the academic world, what does not work is not a problem: one moves on to the next project. In the business world, if something goes wrong, the company's survival is promptly questioned.

The encounters between scientific progress and entrepreneurship have given rise to subversive entrepreneurial figures. Most innovators think of change as an extrapolation of past events. They try to improve on what they already know how to plan and do. The probability (a logical insight, nor a fact of nature) of success can be measured: the risk lies in the measurement. Others who draw inspiration from scientific breakthroughs advance into the dark night of unmeasurable uncertainty. For them, ignorance is no obstacle to action. Their behaviour seems to resonate with the lesson of Frank Knight (1885–1972), an American economist at the University of Chicago, who argued that uncertainty and paradox are rooted in human existence. One of these is Akio Morita (1921–1999), co-founder in Tokyo in 1946 of a company that later changed its name to Sony. A physics graduate from Osaka Imperial University, Akio was the eldest son and heir of one of the oldest sake producers. The young Morita showed a strong inclination for higher studies in applied physics, as well as curiosity and aptitude for the then-nascent electronics, enriched by a passion for music he inherited from his mother and, last but not least, supported by a centuries-old legacy of entrepreneurship.

Are we witnessing an unprecedented intersection between science and entrepreneurship, with those figures sowing the seeds of a new Renaissance? The Renaissance has been a long thread running through the centuries. Think of the European Renaissance of the Middle Ages; the Timurid Renaissance in Asia between the late fourteenth, fifteenth and early sixteenth centuries; the Tokugawa period in Japan (1603–1868); the Bengali Renaissance of the Indian subcontinent between the late eighteenth and early twentieth centuries; the American Renaissance at the turn of the nineteenth and twentieth centuries; the 'New Culture Movement' in China in the 1910s and 1920s. And today? There is no definitive answer. Growing entrepreneurial seeds make no noise. Instead, one hears the sound of corporate crises distinctive of state changes due to significant transformations whose work dismantles everything taken for granted for so long and the din caused by bankruptcies.

Among the hitherto unfinished (if it ever began) works of disruption is the Gross Domestic Product (GDP), whose yardstick is ill-suited to the purpose of the natural unfolding of scientific entrepreneurship for the health of the Earth, which, as Aristotle argued, is subject to corruption and decay. The fact is that national economic accounting struggles to operate as part of a much larger

system of knowledge that goes through a series of upheavals in the unfolding of human history. Unlike nature, which takes great care not to generate superfluous or useless things, GDP is fed abundantly by what is not needed. If the yardstick of economic activity were commensurate with the merit of nature's wisdom, we would find in place of the GDP indicators such as the 'Genuine Progress Indicator'. The GPI incorporates social and environmental factors not measured by GDP, including the costs of ozone depletion, the escalation of crime and poverty on a nation's economic health. The objection that the GPI and other alternative indicators to GDP present non-economic and excessively subjective variables reflects the depth of disciplinary silos in the terrain of economics, knowledge sinks that do reject a transdisciplinary and heterogeneous knowledge package.

ARE WE GOING OFF INTO THE SUNSET OF GDP'S HEGEMONY?

Simon Kuznets, an economist at the National Bureau of Economic Research, presents the original formulation of Gross Domestic Product in his report to the U.S. Congress, 1937.
Simon Kuznets, 1962: *Distinctions must be kept in mind between quantity and quality of growth*.

The 'calf' GDP in the 1930s has long been a 'bull' whose posture is furious and tyrannical.

In a solid Ptolemaic set-up, GDP is at the centre of the system and GDP accountants play the role of intermediaries linking GDP to politicians. Among the latter, there is the one who presides over the entire system to establish a social order that refers to GDP as a natural (if not religious) fact even before it is historical. It matters little that this order imposed by the sphere of the state harms the most vulnerable social groups, if only because the effects of environmental damage fall mainly on their shoulders. Resuming with our words what Shakespeare (1564–1616) in his *Julius Caesar* has Calpurnia say, nothing happens when an ordinary man dies from wounds inflicted on nature. If, on the other hand, it is a political figure or a GDP accountant who dies, storms of lightning and thunderbolts brighten the sky. Ultimately, GDP accountants would rather be perfectly wrong than approach the side of reason, not neglecting the scope of curiosity-driven research for economic indicators off the beaten track.

ACKNOWLEDGEMENTS

Scientific discoveries have consequences that go beyond our preconceived understanding of the world. The change in perspective triggers transformative processes of entrepreneurship. Scientific production is the midwife of scientific entrepreneurship. Both offer humanity the ability to cope with changes in the 'Earth system' due to human activity and open the door to the age when humans and artificial intelligence together will help the Earth survive. The embrace of science and entrepreneurship is, therefore, the answer to the challenges posed by the Anthropocene and the Novacene, as expounded by Paul Crutzen (1933–2021) and Eugene Stoermer (1934–2012) – one a 1995 Nobel Prize winner in chemistry and the other a biologist – and James Lovelock (1919–2022), a pioneer of environmentalism, respectively. The Anthropocene is the geological era purportedly incubated by the first industrial revolution that ushered in human activity capable of exerting a dominant influence on climate and the environment. The Novacene is assumed to represent the age of hyperintelligence from the encounter between human intelligence with its wise and ethical conduct and artificial intelligence with its algorithms and models. The qualities of human conduct allegedly prevent artificial intelligence from causing harm to individuals and society.

Science and entrepreneurship are joined in an embrace involving scientists and humanists, scientists who create businesses from their discoveries and entrepreneurs whose business is due to scientific production. What unites them is being abstruse thinkers whose critical thinking encompasses science, technology and the cultivation of the humanities and fine arts. I wrote Sciencepreneurship inspired by these entanglements and let the mind go to late eighteenth century Europe when St Patrick's College was founded in 1795 in Maynooth, Ireland, which broke down the barriers between disciplines and specialisations. Every student, without exception, undertook a wide range of studies that included, in addition to Theology, Humanities, Rhetoric, Fine Arts, Logic, Mathematics and Physics. Father Nicholas Joseph Callan, Professor of Natural Philosophy at that College, demonstrated the transmission and reception of wireless electricity with a device now known as an electrical transformer. Professor Callan is best known for his research on the induction

coil and for building the largest electric battery of its time. Callan's work contributed to entrepreneurial fertility during the first industrial revolution. The induction coil that Callan invented in 1836 was commercialised by the German instrument maker Heinrich Daniel Ruhmkorff (1803–1877) starting in 1851. The intertwining of the discovery, the entrepreneurial translation and subsequent improvements is such that the invention of the induction coil was attributed to Ruhmkorff.

The University of Maynooth has not ceased to renew the legacy of Callan's time, constantly enriching it with new content. Witness the transdisciplinary architecture of the Innovation Value Institute (IVI). Founded in 2006 in collaboration with Intel, the Institute is an open innovation community that allows an engaged and agile research approach to significant research challenges related to Digital Transformation.

My research work in the knowledge economy owes much to IVI. I sincerely thank the Director of the IVI, Professor Markus Helfert, and all my colleagues for their unwavering support. I extend my thanks to the President of Maynooth University, Professor Eeva Leinonen, the Vice President for Engagement and Innovation, Professor Brian Donnellan, and the entire academic community of this university. My research was echoed in the Italian academy thanks to the commitment of Professor Fabrizio Dughiero of the University of Padua, Pro-Rector for technology transfer and business relations. I thank him for allowing me to initiate ideation processes from the encounter between science and entrepreneurship at the 'Contamination Lab Veneto' Summer School in Cortina d'Ampezzo.

I wish our students, researchers, and the entire academic community to cultivate both the fields of science and humanities to reach the first step of sciencepreneurship. Putting one's mind and foot down is no small feat; it would mean being a citizen of the city of ideas. Obtaining such citizenship is a very demanding thing. If you feel like the young poet Evmenis who, having just composed only one idyll, complained to Theocritus, read Constantine Cavafy's poem 'The First Step'. You will gain courage.

Maynooth, October 21th, 2022

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RAISING THE CURTAIN ON SCIENCE AND SCIENTIFIC ENTREPRENEURSHIP

Science and scientific entrepreneurship have an appetite for new ideas and new things. One and the other meet and confront each other. Theirs is a positive, novelty-generating collision, making available methods and devices that change our standard of living for the better. 'Quiescere in medio mundi' ('To rest in the middle of the world') is not their motto. By dedicating oneself to research, the boredom of treading the same roads every day disappears, and leveraging the passion for knowing what to do with discoveries, the most complex problems solved in the world of research turn into enterprises. Including one or more researchers in the entrepreneurial team eases the transition to the entrepreneurship of the new knowledge emerging from the science lab activity. Accordingly, it is up to the lab policy to convey the attributes of entrepreneurship and its motivation to the investigators. Curiosity, imagination, good reasoning skills and self-confidence are attributes shared by scientists and entrepreneurs. The latter, more so than scientists, often recognise the commercial potential of scientific research and perceive the value in its entrepreneurial spin-off.

Entrepreneurial scientists and scientific entrepreneurs devise revolutionary ways of working, designing and delivering products and services and even seeing the world. The more educated and ambitious generations abandon the idea of the workplace, which, in the words of the humanist Aldous Huxley (1894–1963), leads them to forget themselves and bury their heads in the sand. They want to exist and be important by wearing a suit made of entrepreneurial materials and designed using the experience gained in university and industrial research laboratories. Theirs is meant to be a liveable human experience that is collective, co-creative, constructive and transdisciplinary. It must contribute to enriching the culture of intuition and imagination, of

empathy towards society and the planet. It must educate young people to be guided by the good, and to incorporate communication into action through vision, lived experience design, mental models, and meaningful metaphors.

Co-opetition, i.e. the tension between co-operation and competition, is a generator of ideas and their evolution in science and entrepreneurship. Multilingualism – i.e., understanding the richness of scientific and entrepreneurial languages – offers a variety of ways to translate research into scientific enterprises. Scientific creativity prompts entrepreneurial inventiveness. Ongoing scientific advances in quantum computing are spurring climate entrepreneurship that makes machines exponentially more potent than those available today to mitigate climate change by limiting global warming to the target temperature of 1.5 °C. Other stimuli from those advances are being taken up by pharmaceutical entrepreneurship to simulate ever larger and more complex molecules that become drugs to treat and cure diseases. However, it is not only start-ups that are economically exploiting research resources and findings that are at stake. In the game, entrepreneurial initiatives are also arising from corporate ideas translated into new businesses with the participation of an academic pool of scientists and their students. Technological development within companies can accelerate scientific developments. The discovery of the structure of DNA depended to a large extent on X-ray crystallography of biological molecules, a technique developed by the wool industry for the improvement of its products.

Thus, whenever looking at the advances in science anticipating scientific entrepreneurship, one should not miss Adam Smith's words about 'the ingenuity of the makers of the machines' that anticipates the progress of science. The practical knowledge of metalworkers and, more generally, the intuitive knowledge of each human being indispensable for dealing with the material nature of the world have constituted an essential yet neglected basis of the past scientific and industrial revolutions. In his *Dialogue Concerning the Two Chief World Systems, Ptolemaic and Copernican*, Galileo Galilei (1564–1642) makes Giovanni Francesco Sagredo (1571–1620), a scientific instrument maker, say that he learned a great deal from the artisans of the Venetian Arsenal, at the time a rich source of innovation for the shipbuilding industry.

Other protagonists on the stage between science and entrepreneurship are the polymaths, the personalities who aim to grasp all knowledge. For them, all domains of knowledge are intrinsically bound together. The Andalusian Muslim polymath Abu Al-Walid Ahmed Mohammad Rushd (1126–1198), also known as Averroes in the West, wrote on many subjects, including philosophy, theology, medicine, astronomy, physics, psychology, mathematics, jurisprudence and Islamic law and linguistics. The German Jesuit Athanasius

Kircher (1602–1680), scientific star of the Baroque age and traveller in many worlds of knowledge, fluttered like a butterfly from one field of knowledge to another, between the study of volcanoes and fossils, the observation of microbes under the microscope, mechanical inventions such as automata, the magnetic clock and the megaphone, Egyptology, music theory and comparative religion. The Italian philosopher Giambattista Vico (1668–1744) recommended that young people compare all ideas ≪because the variety of doctrines helps discoveries and advises the right choice≫. From the 1930s to the present day, conflicts between proponents of projects for Unified Science and hyper-specialisation advocates have occurred. With his 1929 manifesto, the Austrian philosopher, sociologist and economist Otto Neurath (1882–1945) launched the project to unify the various fields of science, leading to a revolution in education and thus to a re-imagination of schooling through the creation of pathways for human and relational capital that change the student's mind.

When culture wants to be the engine of evolution, it travels 'the whole orb of science', as the philosopher Giambattista Vico (1668–1744) would say. In science, there are no boundaries between humans and the non-human world, between the imprint of human power on the planet and the changes caused by geological forces. The restless spirits stand at the crossroads between the Republic of Letters and the Republic of Science, drawing on those golden resources that are new insights and new understanding. Stories written by a humanist living a virtuous life as civic-minded and committed to learning might prompt a scientist to new insights and vice versa. Prolific and versatile thinkers burst onto the scene, like Sextus Empiricus, a sceptical Greek philosopher who lived in the second century, trained to live in the certainty of uncertainty, conceiving the most varied scenarios and designing the actions to be implemented. They combine science and entrepreneurship and the two with nature, pursuing a multifaceted and multifaceted knowledge associated with the ability to reach high, see beyond and then leap forward.

Renaissance, Reformation, Scientific Revolution, Enlightenment, Industrial Revolution, and Capitalism in its various forms (corporate, molecular, family) were phases of transformation of social and productive structures brought about by discontinuity. Today, we live in unprecedented convergence in various scientific and business fields. The new algorithms of the knowledge age are forcing many scientific provinces to converge to form the NIBC world – Nanotechnology, Information and Communication Technology, Biology and Cognitive Science. Cloud and quantum computing, e-commerce, mobile internet, IoT, robotics, new materials, artificial intelligence, genomics, nanotechnology and other scientific and technological advancements are

challenging entrepreneurship by triggering changes in business models and blurring industry boundaries.

In the intermingling of science and technology, scientific entrepreneurship is being brought to a high temperature. Educators, scientists, artists, writers, innovators and entrepreneurs are the athletes of social progress fuelled by sustainable and environmentally friendly economic development in the current period of revolutionary change. They all aim to strengthen the four pillars of sustainability that concern living beings, sociality, the economy and the environment. Universities that master the entire knowledge chain – from its creation and dissemination to entrepreneurial conversion – pay attention to them. With universities intertwining scientific and entrepreneurial talents to translate the clothes of science into entrepreneurial expectations with high potential for qualitative and sustainable growth, the conditions will be favourable for creating scientific enterprises. With universities intertwining scientific and entrepreneurial talents to translate the garments of science into entrepreneurial expectations with high potential for qualitative and sustainable growth, the conditions will be favourable for creating scientific enterprises. These are committed to using what is already known in new ways and exploiting discoveries. Given the changes in the Earth system, starting with climate transformation, qualitative and sustainable growth is imperative for companies moving in parallel with the moving forward of the knowledge frontier. The rules adopted for value-creating business development must take this into account. The code of quality and sustainable growth requires reformulating rules like those recommended by McKinsey, starting with 'prioritise profitable, fast-growing markets' and 'outgrow your peers'. In turn, public policy will have to address the issue of the burden to be borne in the transition from quantity to quality of entrepreneurial growth. Can the trade-off between one and the other be eliminated or acceptable, and how? In any case, it is up to those policies to encourage responsible entrepreneurship, which cares about the collective well-being and thus reduces or eliminates the negative impacts of its operations on living beings and natural resources. According to Deloitte, responsible businesses curb costs and risks, achieve higher profits and increase shareholder value.

To understand that humankind is an almost imperceptible point in the cosmos, not the master oriented for his sole convenience to exploit natural resources without limits, one must have walked the pathways of scientific thought and literary-philosophical thought up to the present day. The first path was unlocked by Nicolaus Copernicus (1473–1543), Tycho Brahe (1546–1601), Galileo Galilei (1564–1642) and Johannes Kepler (1571–1630);

the second, by Michel de Montaigne (1533–1592) and William Shakespeare (1564–1616). In this regard, the French philosopher wrote:

> *Can anything be imagined so ridiculous, that this miserable and wretched creature [man], who is not so much as master of himself, but subject to the injuries of all things, should call himself master and emperor of the world, of which he has not power to know the least part, much less to command the whole?*.

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SCIENCEPRENEURSHIP IN A RADICALLY UNCERTAIN WORLD

The economic booms of the second post-war period are now a distant and vague memory. Having emerged defeated from the Second World War, Italy (1958–1963), Germany (already in full employment in 1961) and Japan (already in the 1960s the world's third economic power) recorded 'economic miracles' that led to the belief in unlimited economic progress. Today, those certainties have more than faded; they have collapsed. So too, have the certainties about the validity of disciplinary silos, the wells of knowledge into which experts descend, whether in education, entrepreneurship or other human activities. Strongly intertwined, a series of economic, social, political, environmental and health shocks have put both mass and conspicuous consumption enterprises in trouble. Scientific companies are now on the scene, called upon to meet the challenges we face.

Human beings should be trained to remove the beliefs ingrained in our way of life in pursuing human exceptionalism. Only then can uncertainty nourish creativity for a culturally productive world. By custom and consensus, we are firmly convinced that the Earth and people are strategic resources to be exploited with uncontainable excess, causing corruption, decay and impoverishment. One thinks of the legacy, still difficult to eradicate, of past industrial revolutions that degraded ordinary people to an animated resource, the primary source of energy and poorly paid. This should not be the case, argues Amitav Ghosh in his fascinating essay The Nutmeg's Curse. Following the Indian writer's thought, what is needed is a new 'Grand Instauration', after the one imagined by Francis Bacon (1561–1626), about which we will say later (see Chapter Fourteen). Humankind has to be committed to understanding that the Earth is not something to be grabbed and seized for shaping it at will: for its convenience, said the French philosopher Michel de

Montaigne, as extractive capitalism does, which, moreover, creates systemic inequalities. As we will argue afterwards, the Earth has meaning as a living organism with its natural objects, seas, lakes, rivers, mountains and forests, which, together with all living species, weave relationships with each other, endowed with interpretative and intuitive capacities. Therefore, these natural wholes that characterise the Earth deserve civil rights. This view is the opposite of the mechanistic belief that natural wholes behave like machines made up of parts with no intrinsic relationship to each other.

When we remain imprisoned in our interpretations of reality, our emotional attachments and fears affect our future actions. Once trapped in supremacist beliefs, humans are led to a restrictive interpretation of a radically uncertain world and consequently do not change their stance. Breaking free from the trap is the outcome of human intelligence's ability to recognise and adapt to an environment that is anything but mechanistic. This intelligence is not fixed and measurable with a standard test, being in action an ongoing and changing relational process with nature and, ultimately, with the health of our planet, to abandon beliefs, those fixed stars that prevent our eyes from revealing new patterns. Their recognition is possible with other eyes and languages other than those used during the various stages of the industrial revolution. Hence, the personalisation and diversification of relationships developed by organicism, which conceives each natural whole as one body, takes over the mechanicism that claims to conform to a standardised approach to relations.

From experiencing uncertainty, thoughts can rise, generating ideas whose understanding prompts action. Lacking experience of the consequences caused by uncertainty, being competent on the matter of an uncertain world is different from having an awareness of it. I read what experts have written on the subject, and their reflections convince me. However, I need to comprehend the meaning that the knowledge gained from being involved in an uncertain situation would give me. Humans can bite uncertainty as they eat an egg, in the metaphor of Melanie Mitchell of the Santa Fe Institute and former co-director of Google's AI ethics team. Not tasting an egg is the humanoid robot, a machine with artificial intelligence. Meanwhile, researchers at the University of Liverpool have developed a robot scientist who autonomously conducts experiments in a chemistry laboratory. A cartoon in The New Yorker of 31 October 2002 shows a robot at a workbench, bored and sleepy. Two human assistants comment: ≪The smarter we make the A.I., the less it wants to do our jobs≫ The robot aspires to climb the job ladder, engaging in less and less repetitive and increasingly challenging tasks.

Experimenting humans face the ambiguity of messiness due to uncertainty and confusion and the unambiguous specificity of algorithms to perform