DEPARTMENT OF SCIENCE, TECHNOLOGY,
ENGINEERING AND PUBLIC POLICY

C21st Science Policy

Focus on: Human Intellectual Capital

A Synthesis Report for the UAE Office of Advanced Sciences

About UCL

UCL is one of the world's leading multi-disciplinary universities, with students from over 150 countries and more than 13,000 staff.

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The UCL Department of Science, Technology, Engineering and Public Policy (STEaPP) mobilises science, technology, engineering and policy expertise to help change the world for the better.

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Methodology

The content of this report is drawn from multiple sources and we have used a combination of corresponding data collection and analysis techniques. These included a review of international academic and grey literature on science policy, policy design, and R&D policy instruments; interviews with senior individuals with first-hand experience of the design of national science policy; and multiple trends analysis discussions with the UAE Office of Advanced Sciences team. The research team also benefited from parallel engagement with the staff and experts engaged in the Emirates Mars Mission at the Mohammed Bin Rashid Space Centre. The team has also drawn on findings from previous research. Further details, including the accompanying technical reports, can be found on the UCL Department for Science, Technology, Engineering and Public Policy website (www.ucl.ac.uk/steapp).

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Science Policy for the 21st Century

> Sustained engagement between scientists and policy makers builds relationships and insights across boundaries. It means the selection of issues, the investigations and the findings are better informed and have more impact.

Dr Claire Craig
Director of Science Policy
Royal Society
2016–2019

Developing Science for UAE's Future

Since its independence in 1971 the UAE has implemented a set of development strategies leading to its emergence as a significant oil-based economic power. Over the decades since, its economy, society and culture have evolved significantly. Large-scale investment in national economic development and infrastructure has transformed UAE society. A concern of UAE leaders today is to create sustainable pathways to long-term prosperity and security for Emirati citizens and residents. Science is seen as integral to this ambition, and is recognised as a springboard for the next phase of national development and diversification.

The UAE Office of Advanced Sciences (OAS) is undertaking a series of studies to define and develop opportunities in support of this national ambition. These studies are forward-looking, yet grounded in acknowledgement of UAE's current development profile and its existing knowledge infrastructure and governance configurations. There is considerable domestic momentum behind UAE activities to use science to further national development. In reflecting on similar experiences elsewhere, it is also recognised that the timing of this development is critical. The coming years are likely to be particularly important for developing and embedding science policy to align with and bolster broader national activities and goals.

Science Policy and Leadership

Formulating science policy to maximise the benefits for society is a multidimensional and complex endeavour. Research on the process, boundaries and substance of science policy has undergone various paradigmatic shifts in recent decades. Recent thinking has emphasised the importance of embedding of desired economic and social outcomes within science policy design. Not all science and innovation lead to positive outcomes, however, and a high priority is therefore placed on policy's ability to drive science into positive directions and mitigate against negative consequences.

The UAE's work on conceptualising and implementing science and innovation policy and on promoting science as part of broader culture has much to offer not only to domestic development, but also to wider global learning in this domain.

Science Policy Focus, Capabilities and Boundaries

A science policy designed to advance social and economic capacities pursues several outcomes. First, it has to foster R&D and innovation, and it has to facilitate the production of high-quality outputs from research activity. Equally, it must explore the diversity of pathways between production and uses of science. For this, it needs to foster broad engagement and intermediary capabilities. The building of scientific capacity therefore spans a range of management, engineering, natural, physical and social science skills, responding not only to the needs of individuals, but also organisations and institutions.

This means that in practice science policy needs to foster competence at least three crucial areas:

I. The funding of science and research relevant to national context, need and ambition

II. Human intellectual capital to advance the full span of capacities and capabilities required for a competitive science economy

III. Institutional capacities to join up networks across domains and drive complex and multidimensional initiatives and missions for lasting impact.

This Report

This report results from a joint endeavour between the Science, Engineering, Technology and Public Policy (STEaPP) department at UCL and UAE's Office of Advanced Sciences (OAS). UCL is a world leading university with strengths across a wide range of disciplines and domains. Founded in 1826 with a history of radical thinking aimed at transforming society through knowledge production and engagement, the university has its roots in a quest for progressive public policy.

STEaPP is based in UCL's Engineering Faculty. The department develops new knowledge infrastructures to produce and disseminate expertise for the benefit of society. STEaPP's teaching, research and engagement activities integrate knowledge from diverse social, scientific and technical domains and from academic and practitioner communities. With clear-sighted analysis STEaPP builds new policy insights, capabilities and communities to enhance the societal benefits of investment in science, technology and engineering.

In line with STEaPP's broad ambitions, over the period of April-September 2019, a team of staff members worked with the UAE's Office of Advanced Sciences. Together we explored recent thinking about the design and content of science policy, and the process associated with generating policy for integrating science, technology and innovation with societal aims and ambitions.

This report is a synthesis of that exploration and is based on multiple meetings with the UAE Minister of Advanced Sciences, her team, a range of stakeholders and global experts. It also reflects a targeted desk-based exercise to gather relevant evidence from around the world. The report therefore is broad, covering considerable intellectual breadth and depth. It is designed to give insight into collective analysis about the process and direction of science policy development in the UAE. What this report does not provide is a comprehensive analysis of specific policy instruments, nor does it propose recommendations for specific policy design. Work underpinning this analysis will be published separately. We present our summary in 3 parts:

I. **Global Science of Science Policy** offers a short summary of the global state of knowledge and best practice regarding the framings and tools used for science policy design.

II. **7 Principles for UAE Leadership** outlines a set of guidelines with which to shape science policy instruments for the UAE's future.

III. **Focus On: R&D Funding** draws on these principles in presenting some of the considerations for designing UAE research and innovation funding policy instruments.

Global Science of Science Policy

> Rapidly emerging economies must develop STI policies that reflect their particular and unique context. In general, countries cannot do everything in science. Their funding systems, goals and policies must therefore reflect a very strategic and contextualized perspective.

Sir Peter Gluckman
Chief Science Advisor
New Zealand
2009–2018

What is science policy?

Science policy provides the mechanisms by which public resources are allocated for the conduct of science. This covers multiple domains and a wide range of activities, including fundamental research (enhancing the understanding of phenomena via breakthroughs), applied research (the application of scientific knowledge to practical advances such as technologies), and their connections into commercialisation and marketisation. The latter two areas are the focus of innovation policy; science and innovation policy are highly interconnected policy domains through value chains, institutions, and skilled personnel. Within the umbrella of science policy, there will be multiple constitutive areas of policy instruments, such as the management of funding for research and development (R&D), human intellectual capital, research infrastructure and facilities, intellectual property laws, and more.

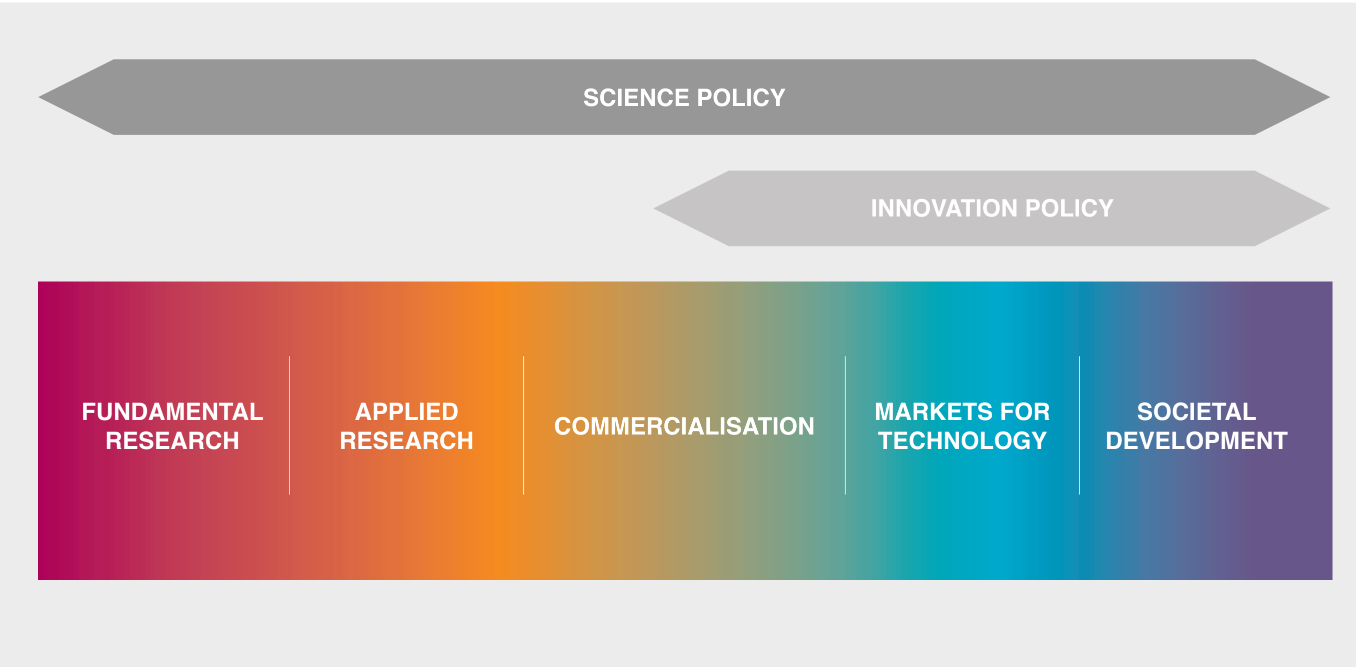


Figure 1. Science and innovation policy are deeply interconnected and span multiple activities

Global Evolution of Ideas

Three frameworks for science policy have evolved sequentially over the past century and have shaped national science policy across the world. They each comprise distinct sets of beliefs about the appropriate roles of actors such as the state, private industry, academia and consumers in enabling good science, as well as provide the justifications for different agendas of policy action. An understanding of the differences in their framing is valuable in setting a nation's science policy agenda.

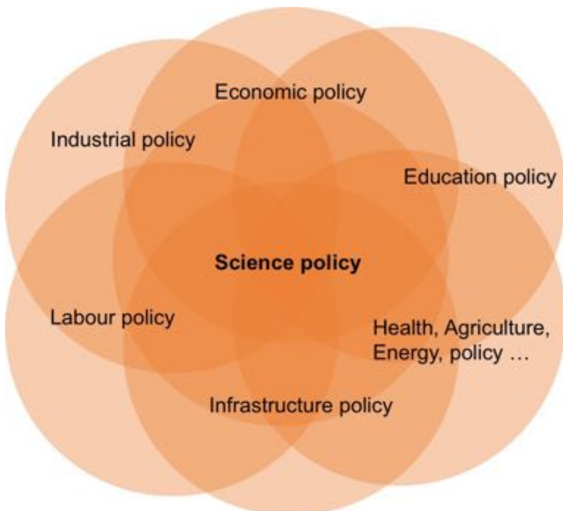


Figure 2.
Science policy interfaces closely with other policy areas

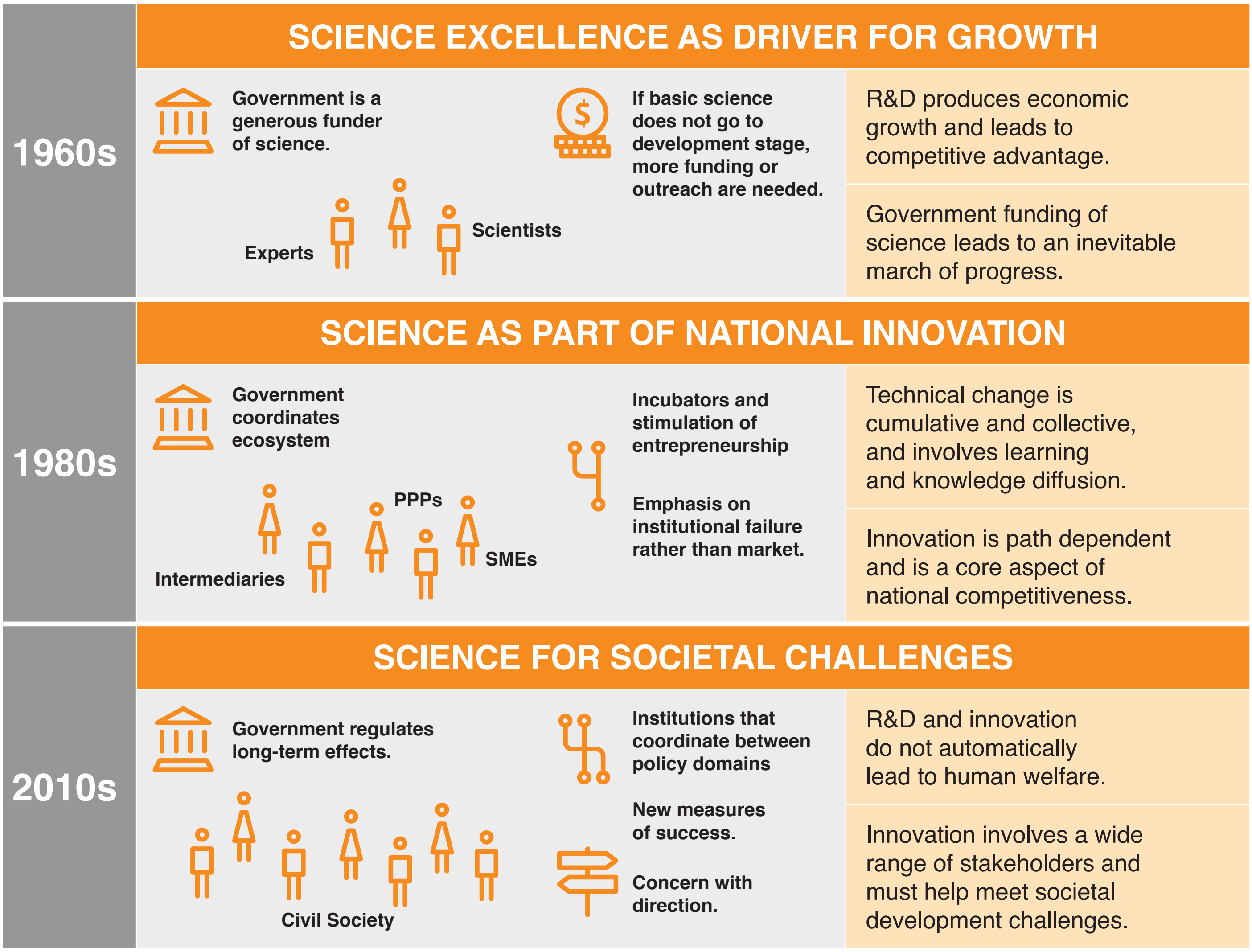


Figure 3. Global evolution of frameworks shaping science policy[1]

Knowledge for Integral Design

What has been learnt about how the ideas above are translated into practical decisions and processes, and about how we can do this type of policy design? The field of the science about science policy itself is relatively young. Much of the body of research in this area has largely focused on either the efficacy of individual policy instruments, or one particular dimension, such as the governance of science policy development. Policy officials looking to structure their processes need a means of navigating and framing the knowledge that they have available to them and mapping the knowledge that they require. We identify three strands of requisite knowledge, covering:

I. **Policy practice.** This is knowledge about the practical processes involved in policy development, including insights about the suitability and effectiveness of different tools for design and analysis, the needed skills and related capacities, and institutional compatibilities.

II. **Policy content.** This is knowledge about the nature of different policy instruments and the choices that shape the details of their design.

III. **Policy context.** This is knowledge about the particular context within which the policy will be implemented. This includes knowledge about its purpose, constraints, possibilities and other considerations such as local cultural, social and economic factors.

1 See Schot, J. and W. E. Steinmueller. 2018. Three frames for innovation policy: R&D, systems of innovation and transformative change. Research Policy, 47(9), pp. 1554–1567.

These sets of knowledge should not be treated as separate strands that are the responsibility of different professionals or individuals. Instead, integral science policy design considers them simultaneously, and reflects their mutual interrelationships within any design processes employed.

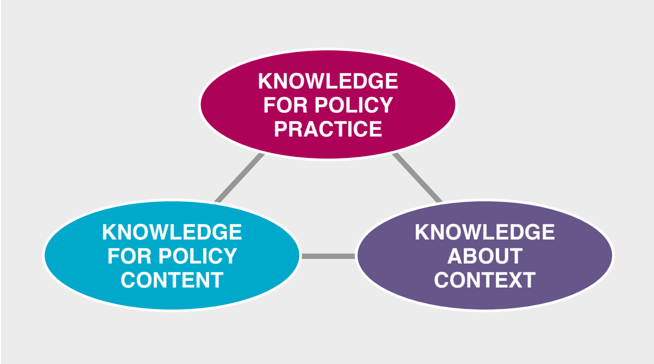
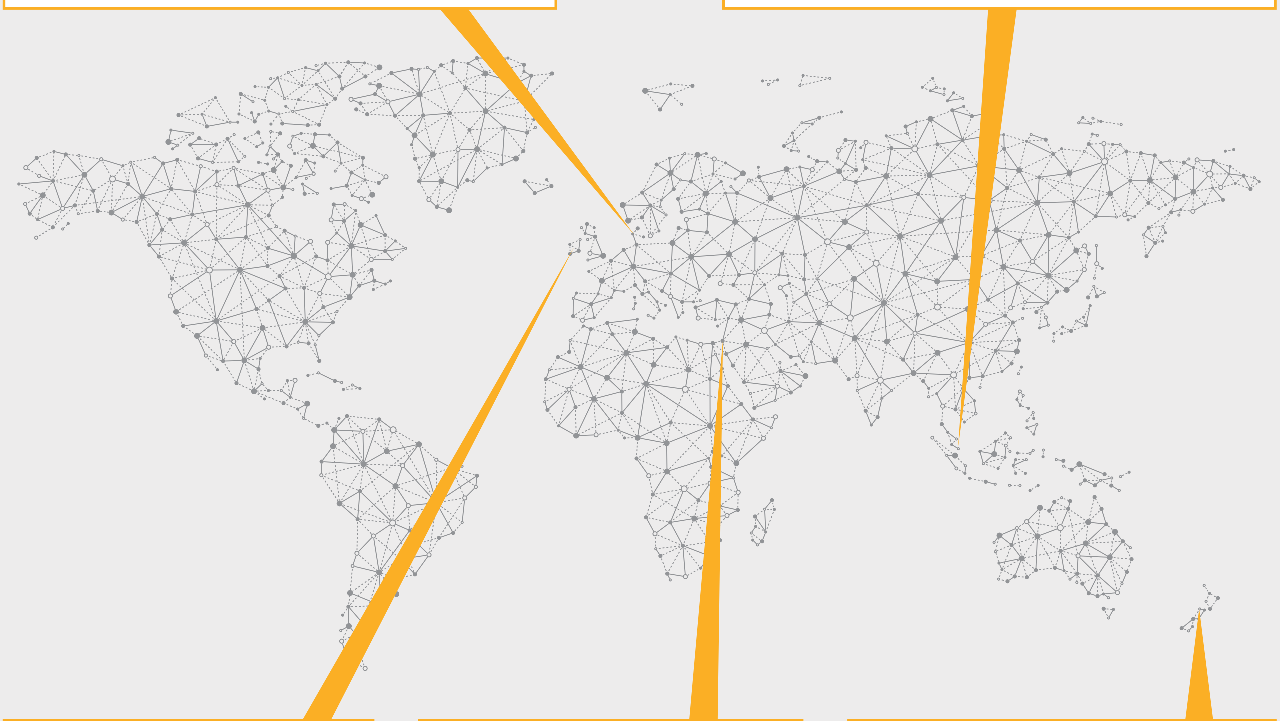


Figure 4.
Three types of knowledge for integral science policy design

Denmark, with a historical background of large domestic multinationals and deep links into Europe, uses a traditional investigator- led system for its science economy. It merged government research institutes with its universities and uses data and policy experiments to continuously adapt its research strategies.

Singapore had little science and innovation infrastructure 40 years ago and chose to invest in two primary areas – life sciences and ICT-engineering. It created its A-STAR Institute, while building a national university system and focusing on attracting multinational companies for investment in R&D.



Ireland used its advantages of being in the EU and company tax incentives to focus its research effort on collaborations aligning commercial sector interests and opportunities. It uses an extensive prioritization process for supporting research.

Israel focused on building a science and innovation economy with focus on communications / defence, digital and healthcare, putting emphasis on deploying a strategy that integrated its geopolitical situation with design of non-educational institutions and development of Universities.

New Zealand has invested heavily in government research institutions to support agricultural research. 30-40% of its research is via institutes (funded by competitive grants) rather than universities. Recently it has an increasing mix of mission-led and impact-focused contestable research.

Figure 5. Small countries, substantial science footprints

7 Principles for UAE Leadership

> Before you talk about funding allocation, you need to talk about the 'what is it for?' 'What is the overarching rationale?'

Prof Graeme Reid
Head of Research Funding
UK Government
2016

Global experiences and expertise suggest that while there is no blueprint for science policy formulation, there are shared lessons that can inform its process of design. For the UAE to provide leadership in science, it is recommended that its future policies and instruments draw on these lessons as a set of guiding principles enabling successful science policy design.

Avoid Pitfalls of Policy Transfer

Some countries have sought to emulate the research and innovation success of other nations such as the USA and the UK with direct policy transfer and adoption. However, experience cautions strongly against direct replication of the design of a science policy instrument. Direct transfer does not recognise the importance of local context. In particular, science policies often seek to influence particular 'tipping points', and so their underpinning rationales are typically not directly scalable other economies. A 'copy-paste' approach in policy learning and transfer also risks abandoning indigenous strength, and fails to consider the distinctive requirements of local long-term capability development.

Shape with Distinctive Context

Closely related is the principle that science and innovation policies need to explicitly reflect the nature of their particular context. Small advanced economies have historically often outperformed large economies in important respects. Research to explain this has shown that the science policy of small advanced economies often very explicitly considers local strengths, constraints and consequences of risk exposure to disruptions – and subsequently generates more suitable, effective and robust policy outcomes. Policy proposals for new UAE science instruments should therefore demonstrate the logic regarding their fit with the distinctive, local context and play to its particular strengths.

Use Forward-Looking Evidence

In order to craft relevant, locally-suited policy, the evidence used for its design needs to be forward-looking. When primarily backward-looking analysis is drawn upon, a policy's capacity for desirable future impact is significantly weakened. Many of the tools commonly used in analysis for policy design (e.g. historical trends and current state benchmarking), however, produce little useful futures evidence. Widely recognised guidance or standards for assuring the forward-looking quality of an evidence base is currently limited. To bridge this gap, Figure 7 offers a checklist of 'Future Evidence Requirements'. These requirements offer a checklist for primary assumptions made about the future that can be tested using insight from relevant evidence gathered about the following factors that explicitly or implicitly shape proposals: the goals; driver of change; options; pathways; and possible constraints and disruptors shaping a policy proposal.

Make Explicit the Rationale for Change

The logic structuring a particular policy formulation should be clearly articulated in order to provide the basis for any justification of its adoption. By detailing what problems are to be addressed and providing a clear rationale of how the critical mechanisms of change are to be activated alongside what actions and under what conditions, a policy's likely outcomes can be more accurately assessed. This also enables other actors more broadly in the science policy system to quickly understand how their actions might be influenced by a new policy.

Explore Robustness in Outcomes

Robustness refers to the desirable design quality trait where policy maintains functionality despite changing conditions. To achieve this, key assumptions made first must be made explicit (see Figure 6). The implications of any variation in the state of these assumptions is then tested across alternative futures. A common way to structure such a stress-test exercise is to frame a set of 'what if… ?' questions (e.g. 'What if policy goal A changed?' 'What if this critical agent's agenda changed?' What if market mechanism B was disrupted by a global event?'). In cases where the same what-if questions are then applied to alternative proposals considered for a policy intervention, such conceptual simulations clarify the trade-offs between them, and enhance the rationale by which a particular policy design or instrument is chosen.

Design for Modularity

Another mechanism for ensuring robustness in policy design is to use a modular architecture where policies are framed with their own coherent logic, but give attention to interdependencies with other policies. Each policy proposal must justify the mechanisms by which it joins into the wider policy ecosystem, but remains robust to any potential changes elsewhere in that ecosystem. This is particularly legitimate for science policy where many overlapping subjects and policy concerns come together, such as human capital, funding and science infrastructure. Modular design enables evolving, dynamic and experimental use of different policy instruments.

Utilise Design for Building Capacity

Policy design as a process has the potential to result in content-driven outcomes such as new ideas and policy formulation, but can crucially also act as a collective learning process for the actors contributing to it. By intentionally structuring policy design processes in a participatory way from the outset, that learning enhances not only the substantive and procedural capacities of those directly involved in the policy team, but also those of actors more widely across the national science system.

In order to enhance the use of forward-looking evidence and explore robustness in outcomes, we benefit from 3 stages of activity:

I. **To unpack** some of the different types of forward-looking evidence that there can be to inform policy design. (See figure 6 for the 'Futures Evidence Landscape')

II. **To review** what assumptions are being made about the state of available futures evidence underpinning a new policy proposition (See Part 1 in figure 7 for the 'Futures Evidence Canvas').

III. **To enhance** the robustness of these assumptions made by considering 'what-if' these assumptions changed? What implications would this have for the performance of our policy and its consequences. (See Part 2 of the 'Futures Evidence Canvas', figure 7).

I. Unpacking of forward-looking evidence

The evidence base for future policy content spans three domains: 1) the first provides evidence of the assumptions made about the direction pursued with a policy; the second contains assumptions about the behaviour of the wider system within which policy will operate; and the third provides us with intelligence about different pathways for action that can be pursued. Within these categories are 10 more specific types of future evidence that can be elicited and analysed.

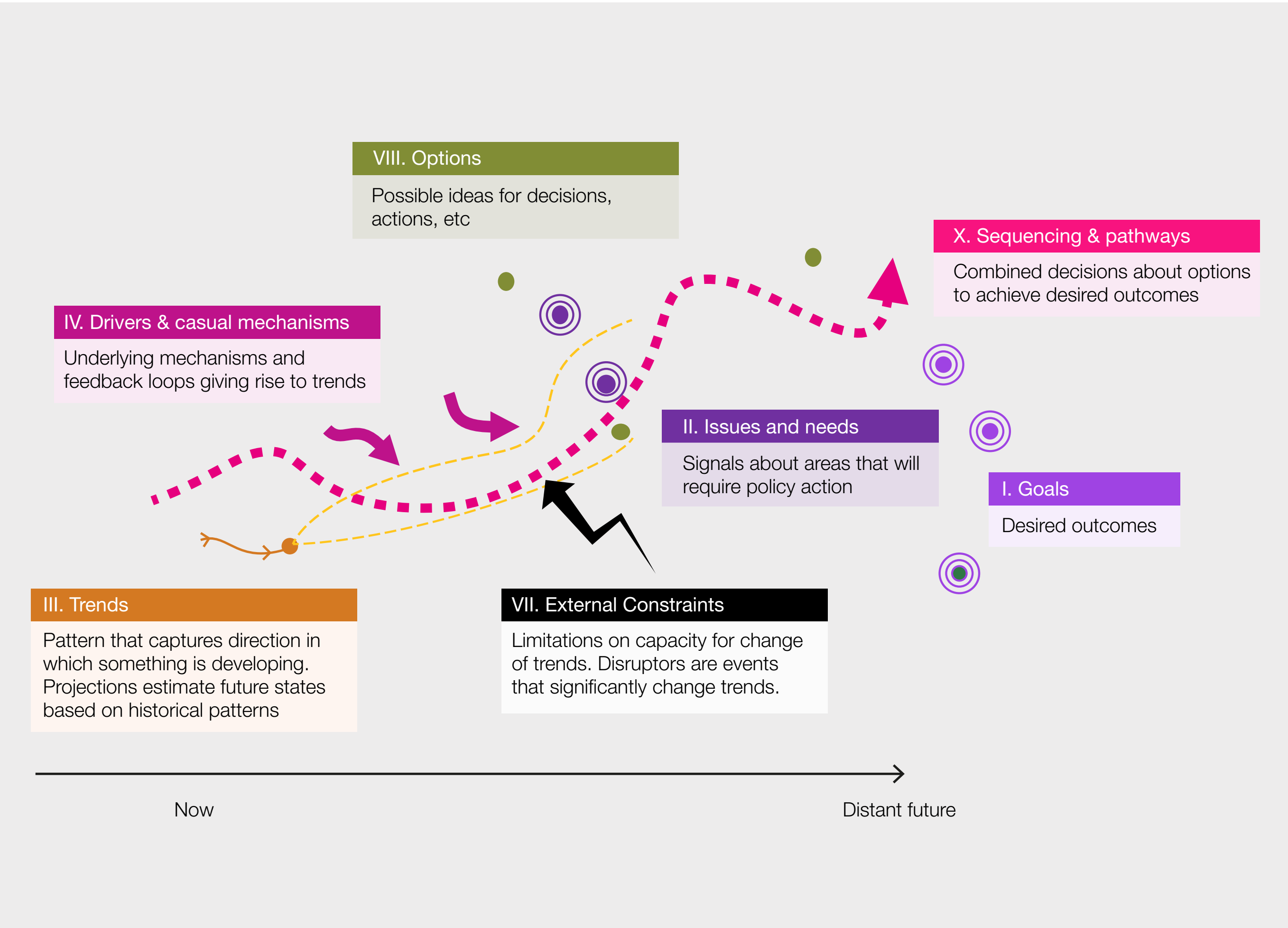


Figure 6. Future Evidence Requirements

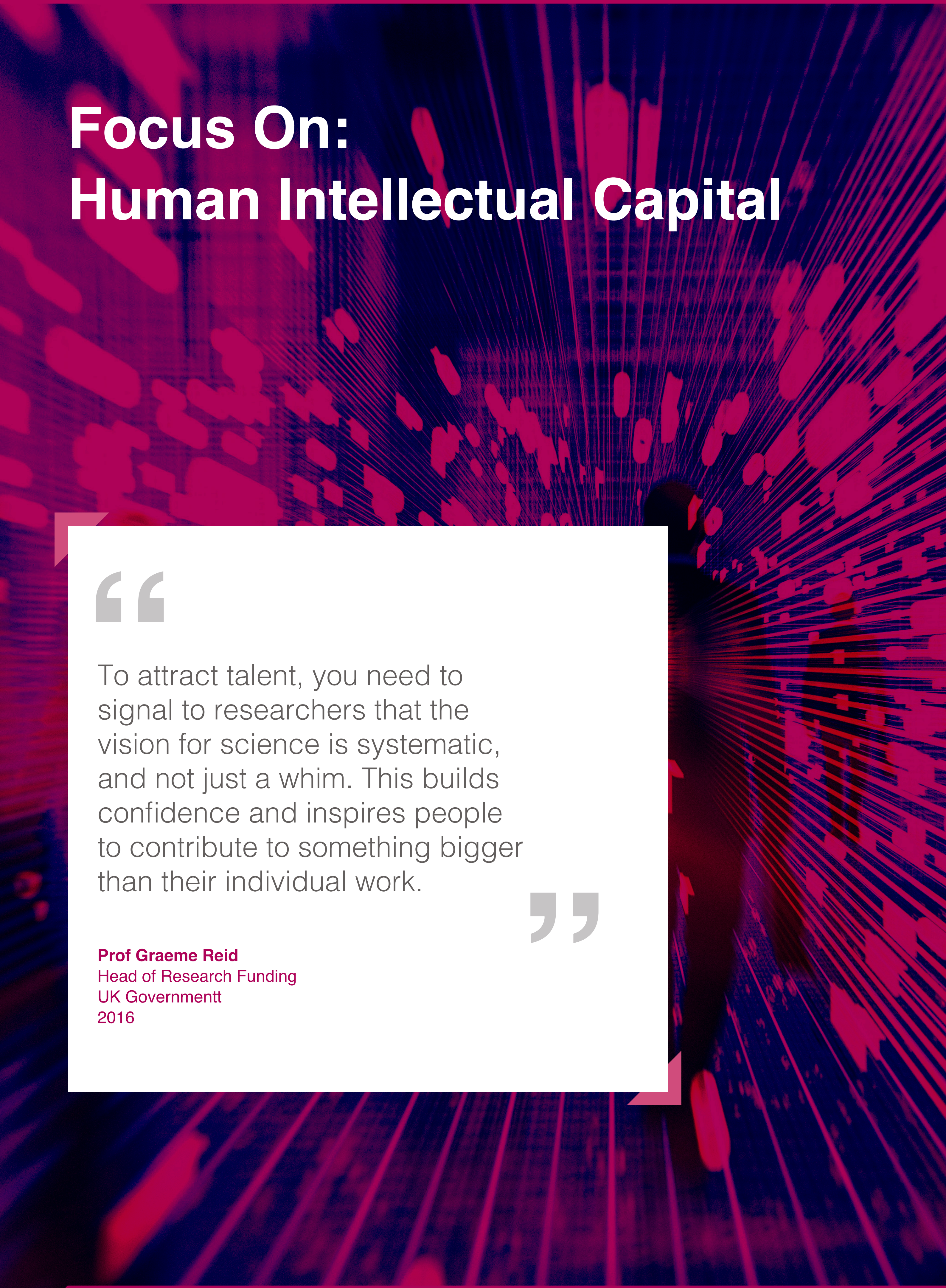
II. and III. Reviewing and enhancing the forward-looking evidence base

By systematically considering the state of assumptions made about the futures evidence landscape underpinning a new policy proposition, we can rapidly assess the comprehensiveness of the evidence base.

	Future Evidence Type	Guiding question to explore requirement
Setting direction		***Where do we want to head?***
	I. Goals	What do we know about the specific outcomes being pursued? Priorities? Values?
	II. Issues & needs	What is the problem we are seeking to resolve? What are the needs to be addressed?
Understanding system behaviour		***What do we believe about how the world behaves and will behave?***
	III. Trends	What are the patterns associated with the development of factors of significance? What is the difference between historical and projected patterns?
	IV. Drivers & causal mechanisms	What will drive behaviour of the science policy system? What causal relationships and feedback loops osf influence exist?
	V. Structures & relationships	What are relevant elements of the science policy system? (e.g. policy structures, institutions, economic, legal, etc). What are the relationships between them?
	VI. Agents & agendas	Who are the key agents and actors? What priorities might drive their behaviour?
	VII. External constraints	What external constraints will influence possible science policy actions? (e.g. resources, regulatory, etc). What might radically threaten or disrupt the system?
Developing pathways		***What do we know about how to move towards our intended direction, within what we know about system behaviour?***
	VIII. Options	What are possible ideas or decision options for science policy action?
	IX. Trade-offs	What are the trade-offs between these?
	X. Sequencing	What is known about path dependencies impacting on intended policy action, etc?

Figure 7. Future Evidence Requirements

	A	B		
	What evidence do we currently have for this wrt a policy proposition?	What confidence do we currently have in the robustness of this evidence?	What if' these assumptions changed?	What further data would we want for enhance confidence?



Focus On: Human Intellectual Capital

> To attract talent, you need to signal to researchers that the vision for science is systematic, and not just a whim. This builds confidence and inspires people to contribute to something bigger than their individual work.

Prof Graeme Reid
Head of Research Funding
UK Governmentt
2016

People are the heart of science. Whilst investment in physical equipment and facilities may be crucial, that investment will only yield benefits if the human capacities for experimenting and innovating with those facilities are available.

Science policy frameworks have evolved over the last decades, and with them the ideas about the requisite human competencies or ‘capital’ for a resilient national science and research base. Up until the 1980s, the emphasis was on development of scientific human capabilities that would drive growth and development. During the 1980s and 1990s, a new argument took root in which attention shifted to a wider set of capabilities needed to create innovation from science. Those competencies have since been understood be distributed in different ways across public and private sectors.

In recent years, the UAE has joined other countries in looking to science and innovation as important apparatuses for achieving national goals and addressing critical, specific issues, such as climate change and inequality. The kinds of human competencies that are now believed as requisite for addressing these developmental goals are far broader than those related only to the generation of scientific knowledge. They include the ability to frame complex and multidimensional problems that cut across disciplines and fields, and the ability to draw on and synthesise different types of knowledge into applicable insights. These abilities are now seen as integral to the intellectual capital for science and innovation.

In summary, the development of human intellectual capital for a transformative national science capacity is enabled by supporting learning and continued development of all three fundamental types of knowledge (formal - ‘what’; tacit - ‘how to’ and meta – ‘how to support others’) throughout the lifecourse.

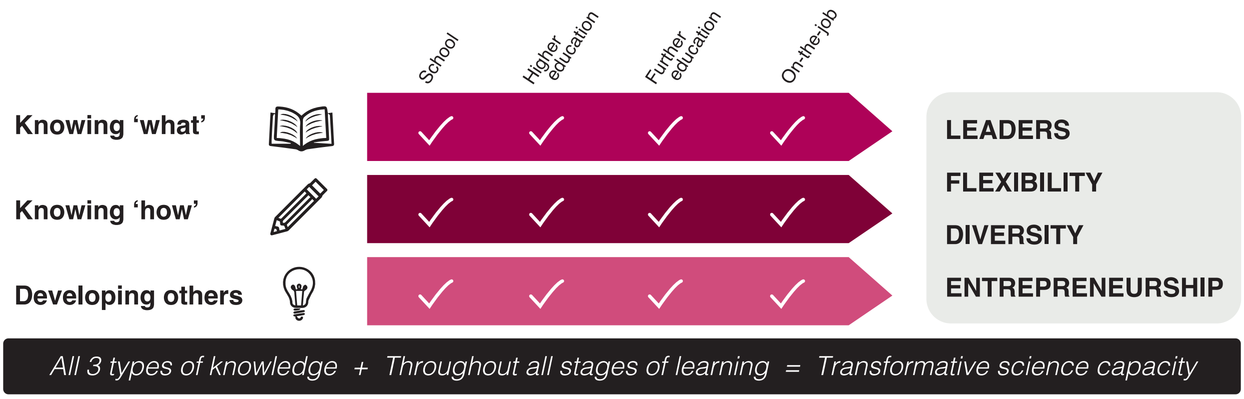


Figure 6. Synchronous, continuous and mixed learning to develop the national human intellectual capital for a twenty first century science capacity

Intellectual Capital for Science

Human intellectual capital is component of national intellectual capital (NIC). NIC attempts to capture the value held by a nation in its intangible assets: such as human knowledge, intellectual property, institutions such as markets, and the capacities of businesses to incorporate new technological innovations.

This concept values an economy not solely on the accountable or physical assets it possesses, but also its intangible assets. Human capital is a pivotal part of this concept: the sum or all the skills and knowledge that the denizens of a nation can render in support of national goals.

Distinctiveness & UAE Human Capital

The UAE is a place where national strategic vision and leadership have profoundly transformed a country within just a few decades. The UAE has a unique demographic situation with Emirati nationals (~11% population) significantly outnumbered by a large expatriate worker population hailing from countries such as India, Pakistan, as well as other Asian and European nations. Emirati people are typically highly connected and with great awareness of global trends in terms of what innovations are happening elsewhere. In the context of making science an integral part of vision for the UAE's future, it is critical to orient any engagement with the national human capital dimension within this unique situation. The question is therefore how to best engage with human capital development during this phase of science policy development? What policy instruments and ideas exist to transplant existing human capital into new sectors and encourage these to flourish anew?

An Anatomy of Human Intellectual Capital

The human capital of particular concern to this report is the ability of someone to perform labour that adds value to the UAE's science and research vision. In science and research, human intellectual capital is important for generating break-through knowledge, problem-solving, generating value from intellectual property, and enhancing usefulness of science products. Human capital is not only about the formal knowledge that individuals can bring to bear on a problem, but also about their tacit knowledge of how to perform tasks and how effectively they are able to pass that knowledge on to others.

The accumulation of different types of knowledge, and development of individuals' capacity to reason about them, constitute the foundation of the cognitive and intellectual assets within an individual.

Generating, nurturing and maintaining human capital requires understanding of learning processes and the ways that knowledge can be transferred across an economy. Human capital is rarely static; it is something that is constantly changing and developing and emerges from combination of knowledge, habits, personal and social attributes.

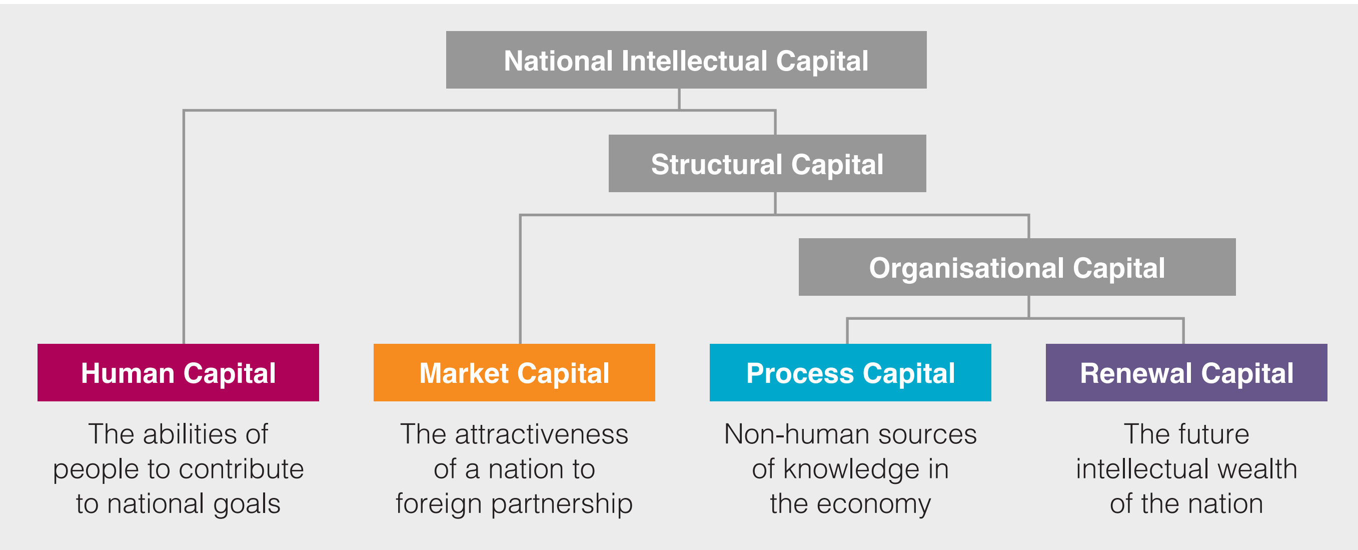


Figure 7. National Intellectual Capital for C21st Science Policy includes Human Intellectual Capital

Investment into Transferable, Absorptive Capacity

Unlike other types of capital, human capital is inherent in individuals. It is thereby a national asset that cannot be owned. This also means that it is mobile, following the movement of people should they chose to locate elsewhere, or work in different environments on different tasks.

Human intellectual capital accumulates with skills and knowledge required for specific tasks. As tasks can be similar across research areas, or across public and private sector research activities, these skills are transferable. These skills also enhance the UAE's 'absorptive capacity', which is its capacity to import external science and innovation developments into the UAE and apply them to desired ends.

Monitoring & Measurement

A number of processes are currently being developed to compare and benchmark human intellectual capital indices at the national or regional level, such as the 'National intellectual Capital measurement Model'. This system includes variables that extend beyond human capital and draw on the International Institute for Management Development (IMD) databases. It should be noted that these benchmarking methodologies have originated from the corporate and organisational management sectors and have no known use to date in informing policy design.

Drivers for C21st UAE Science & Human Intellectual Capital

Coordinating Lifelong Policy Support for Intellectual Capital

At the level of the individual, the development of their intellectual capital for science spans their lifetime of learning. A simplified model typically maps that learning across their formal educational pathways (see Figure 8).

Within the school environment, individuals learn the basic concepts, languages and practices specific to particular disciplines, including the sciences. Later, in higher education, that knowledge specialises, as well as expands with greater tacit and meta knowledge about the socioeconomic context of scientific enquiry. Learning in further education and workforce training then continues to 'upskill' scientists, technicians, and other professionals working within science and innovation sectors. Typically, this knowledge offers insight into emerging ideas or trains in specialised competencies.

This model of linear learning progression is of course highly simplified. In practice, the sequence of knowledges learnt may vary significantly.

A recognition of the lifelong journey of learning highlights two requirements for C21st human intellectual capital for UAE science policy. First, it highlights that as scientific work requires deep understanding of disciplinary subjects, that deep subject knowledge must be clearly integrated into school curricula and offered in formal education. Second, research has shown that both inside and outside of compulsory education, learning is a function of a learner's motivation, interests and opportunities. Both of these insights require coordination of multiple policy domains that are likely be subject to different ministerial portfolios, such as education, labour and economic policy.

The Type of Knowledge	Formal Knowledge	Tacit Knowledge	Economic Metaknowledge
	Knowledge about particular facts. Codifiable and teachable.	Skills for practical tasks Difficult to codify and teach. May require learning-by-doing	Knowledge about how to transfer and manage knowledge
	"Knowing what"	*"Knowing how"*	**"Knowing how to teach"**

Figure 8. Types of knowledge within Human Intellectual Capital development

Fostering a National Culture of Science

National culture is an integral component of the national science and research base.

Research has shown that while humans share the same fundamental cognitive structures for learning, many of the differences in individual intellectual capital are shaped by their cultural and societal context.

Of especial significance to the UAE's ambition to transform its national scientific base within a 10-year period, is that much of the human capital required for this transition must be developed via highly purposeful and intentional learning. Intentional learning is strongly driven by the motivation for learning by an individual. In turn, this phenomenon is strongly shaped by cultural context. Motivations for learning are shaped by the goals for learning, and these are typically shaped and articulated by formal education experiences, as well as family and societal expectations.

The perceived attractiveness and social acceptability of science as career pathways in the UAE is lower than those for careers in e.g. engineering or roles in government and the oil sector. Young Emiratis appear to perceive careers in basic, applied or translational science as riskier undertakings in terms of their long-term well-being than other routes available.

How is the desired cultural change and elevation of science as a career path inspired? Learning about science needs to be valued more by young Emiratis. They need to be supported in building their science identity and science capital into their day-to-day identities in a way that dispels careers in science as neither unconventional or disadvantageous. Science policy has a role in ensuring that science is no longer seen as separate from culture, but instead an integral part of national culture. This can partly be accomplished by building on Emirati ethos for contributing to the future development of their nation, and developing and broadcasting clear narratives about the role of science within the national visions and aspirations.

Educating for Multiple, Transferable Knowledge Types

The structure of a learning environment is a major influence on the types of knowledge and human capital that it fosters for science. In order to facilitate deep and long-term learning, learning environments need to enable an individual to coordinate multiple cognitive processes. Environments that actively support iterative reflection by the individual on their learning are demonstrated to be most effective in facilitating this.

For the design of science policy, this promotes the value of enquiry-based pedagogy across the multiple learning environments employed in the development of national science human capital.

Enquiry or problem-based approaches to learning and development utilise real-world issues to de-emphasise learning by memorisation. Instead they increase motivation by an individual to learn the ways by which interesting solutions can be generated. This not only nurtures curiosity, but also promotes the competencies needed to structure complex problems and systematically define boundaries on challenging enquiries. These skills are critical enablers of developing scientists who contribute to national development by exploring the alignment of their work with societal development interests. It supports scientists in transcending the the linear ideals of knowledge-to-innovation generative models that became highly popular during the post-1950s period and often persist today.

For illustrative examples of the ways that problem-based and experiential pedagogies have been translated into curricula and tested in multiple disciplinary environments, see UCL's 2-week 'How to Change the World'[1] programme and its Connected Curriculum. Though these examples are specific to higher education, their philosophical underpinnings and principles can be transposed to other educational environments.

These problem-based and experiential learning activities are typically undertaken as collaborative, group-based projects. This encourages individuals to learn to integrate diverse types of knowledges, perspectives and experiences. The data shows that this results in enhanced confidence of learners to not only apply that knowledge on unseen future problems, but also increased confidence to adapt and transfer that knowledge into unfamiliar contexts.

Developing 'Know-How' Capital

Tacit or 'know-how' knowledge also warrants separate consideration when exploring pathways for transforming a national science ecosystem. This concerns knowledge of the procedures for evolving ideas into action and getting tasks accomplished in more effective and efficient ways.

For the UAE's vision for its science ecosystem, there is a particular need for developing know-how around the 'proof of concept phase' in a science and technology project. This phase occurs when science has produced an idea for application, but a barrier persists to its uptake into markets.

As consequence of its nature, know-how is a knowledge that is challenging to transfer between individuals via codified mechanisms such as textbooks or manuals. Instead, it is typically learnt first-hand during the execution of a particular task.

Therefore, effective learning environments to foster such know-how development are typically collaborative settings that encourage collective reflective learning (*see previous section*).

1 https://www.ucl.ac.uk/steapp/study/professional-education/how-change-world
https://www.ucl.ac.uk/teaching-learning/sites/teaching-learning/files/connected_curriculum_brochure_oct_2017.pdf

Diversifying Future Pathways

For a C21st networked, multi-pathway and systems-based approach to developing the UAE science ecosystem, there need to be numerous pathways for the development of human capital. Employment, knowledge transfer, and collaboration require both availability as well as visibility of multiple routes for engagement.

At the individual level, this means that those enrolled on science education programmes need to be provided with post-graduation employment ‘destinations’. Global experience shows that such pathways are significantly expanded and strengthened with partnerships on educational programmes (e.g. science degree sponsors or partners who act as ‘problem owners’ for applied degree projects), or immersive placements to institutionalise regular training transfer over intensive time frames.

Other policy instruments provide networking or brokerage platforms for science and innovation actors. These exist in diverse formats, such as innovation districts, sector ‘catapults’, policy ‘laboratories’ etc. They usually offer platforms to bridge the science and research bases of the public and private sectors. The UAE notably has a very high share of researchers in the business sector (~60%). This is not, however, reflected in the level of knowledge and technology outputs from this sector. Though there are likely multiple explanations for this pattern, the diversification of pathways for application and transfer of that private sector knowledge will likely lead to greater innovation across the national science base.

Lastly, through the provision of clear touch points, such platforms also facilitate knowledge transfer and human capital development with sectors other than science, e.g. where individuals without a traditional science degree are able to bring their logistics or entrepreneurial know-how into the science ecosystem.

Attracting & Retaining Talent with a Vision

Until recently, a high proportion of young Emiratis spent time outside of the UAE during at least part of their higher or further education learning. There are some indications that this trend is decreasing, however, which could signal a need to establish alternative pathways to sustain that historic international learning and know-how transfer.

The UAE science and research sector is itself very internationally dependent, with 64.2% of peer-reviewed research journal publications resulting from international collaborations. The national human resources challenge of achieving both high international talent retention as well as attraction is therefore also an issue of science policy.

Other small, rapidly developing science and industrial base nations, such as Israel and Singapore, have experienced similar challenges. Some have relied on the provision of citizenship and salary premiums for both attraction and retention of knowledge workers, though data suggests that salary and remuneration alone are insufficient for long-term know-how retention. Instead, experience suggests that migrated talent remains rooted if they feel partial ownership of a national, cultural vision. There is therefore a critical role for national science policy to provide clear leadership and commitment to a national vision of science that is open to a diversity of contributions. It needs to give confidence to those making life choices that the national vision includes them and has a clear role for science.

Lifting Scientists into Leadership

One challenge affecting the retention of science talent is the perceived 'ceiling' on development of leadership skills and capabilities of UAE scientists. This counteracts their motivation for continued learning and participation in the national science ecosystem.

At the individual level, senior scientists face difficulties in gaining promotions to managerial roles – an achievement of significant cultural value. There is a role for human intellectual capital policy to promote personal development opportunities, as well as prospects for networking, and sharing of experiences. It also merits provision of additional platforms to distinguish achievements, such as with prizes, fellowships, etc.

At the institutional level, leaders can be further supported to participate in institutional-level relationships. Global experiences with policy programmes that offer long-term access to opportunities for reflection with peers on the challenges faced have proven effective in nurturing leadership for science and build a connected 'community of practice' around research and innovation.

Championing Diversity of Talent

Richness in intellectual capital is generated from the interactions of diverse perspectives and knowledges. The UAE as a nation has a history of looking beyond its borders for ideas and inspiration, as well as an openness to changing conventional profiles of participation in specific sectors or tasks. Notably in science, a gender distribution with primarily women prominently active in academia and STEM subjects is one illustration of such Emirati championing of the diversification of national talent. National science policy will benefit significantly from exploring how that diversity contribution can be further nurtured as a distinctive strength within the global science system.

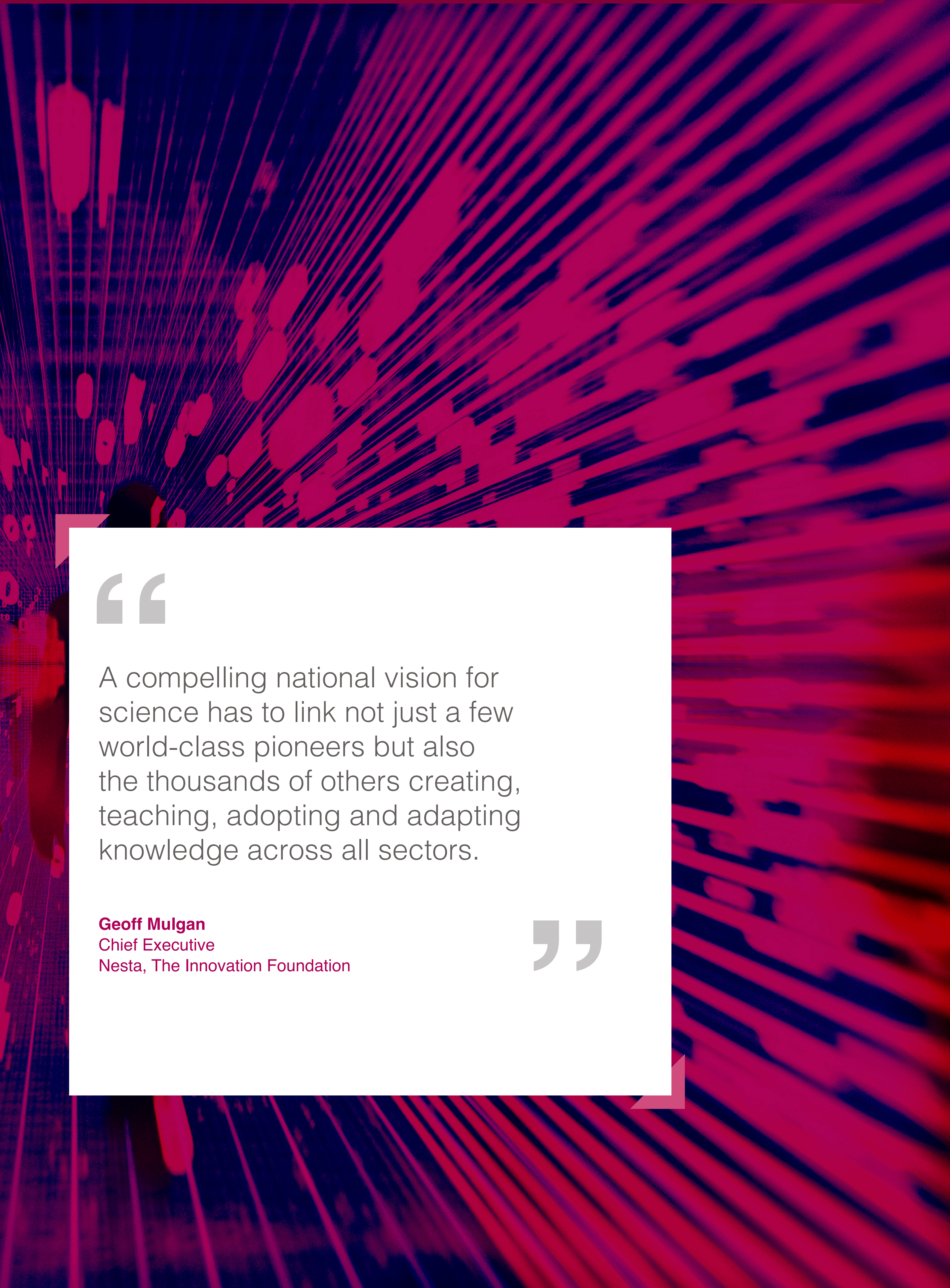
Stage of Learning	Schooling	Higher Education	Further Education	On-The-Job
Formal Knowledge	●	●	●	●
Tacit Knowledge		●	●	●
Economic Meta Knowledge		●	●	●

MOTIVATION INTEREST OPPORTUNITIES

Figure 9. Stages of learning in Human Intellectual Capital development

> For a national culture of science, people need to be able to build an identity of science and capital for science into their day-to-day identities.

Katherine Mathieson
Chief Executive
British Science Association



> A compelling national vision for science has to link not just a few world-class pioneers but also the thousands of others creating, teaching, adopting and adapting knowledge across all sectors.

Geoff Mulgan
Chief Executive
Nesta, The Innovation Foundation

DEPARTMENT OF SCIENCE, TECHNOLOGY,
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UCL

Dr Ine Steenmans

Ine focuses on analysis that enhances the future robustness of policies. Her work combines and adapts methods and processes from a wide range of fields, including policy foresight, design, and systems analysis, and seeks to improve their usefulness and usability by policy makers.

Mr Luke Bevan

Luke explores the conceptualisation of uncertainty in climate and energy systems modelling. His research is underpinned by an interest in the interface between science and its application to real-world problems.

Dr Chris Tyler

Chris explores how policy makers use scientific evidence. Prior to joining UCL, he spent five years as Director of the UK's Parliamentary Office of Science and Technology (POST). Before that he was the first Executive Director of the Centre for Science and Policy (CSaP) at the University of Cambridge.

Prof Joanna Chataway

Jo has more than 20 years of experience in the areas of innovation and social and economic development – particularly in the analysis and evaluation of investment in research and innovation, including what sorts of instruments translate research into useful innovation.

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