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Royal Society
Mathematical Futures Programme

Scenarios for the future of mathematics

Firetail

Why are we thinking about scenarios for the future of mathematics?

Introduction

'The future is unpredictable, but we can map possible trends to understand where we might be heading. The future of maths is no exception - a vital skill that underpins the working of society and the economy. But...

- Imagine a world where the only people with maths knowledge were those who could make profit from it - and potentially exploit those less skilled.
- Or an alternative world where there's public investment in maths and all citizens have the skills they need - boosting innovation and wellbeing.

Where would you rather be? And how might we get there?'

Why are we thinking about scenarios?

The future is uncertain. There are many different factors that might influence the course of future events. The world has been caught off guard by a series of unexpected events - from the pandemic, to shifts in the global political order, to war in Europe. We do not want to tie our plans and big decisions to a single set of imagined future events. While we can't predict the future, we can think about a range of different futures. The purpose of thinking in terms of scenarios is to help cope with this uncertainty.

A scenario is a story about the future. It is a plausible vision for what the world might be like. Scenarios should promote constructive, action-oriented discussion among stakeholders, with a sense of urgency on what is at stake, challenging us to think more ambitiously.

The purpose of these scenarios is to prompt debate about the future of mathematics in society: how is the importance of mathematics changing, and what its role be for education, society, the economy, and citizenship? We have been through a process of thinking about what forces might affect the role and importance of mathematics in the future. Through research with a broad set of experts and stakeholders we have narrowed have chosen two big uncertainties:

- What will drive people to acquire skills in mathematics? Will it be driven by leadership from policy makers or a rear-guard response to a crisis?
- What will be the main purpose of mathematics in society? Will it be considered a public good or a private good? Will maths be oriented towards solving collective challenges or for personal benefit, such as employability?

The four scenarios we have developed are the permutations of the extreme answers to these questions.

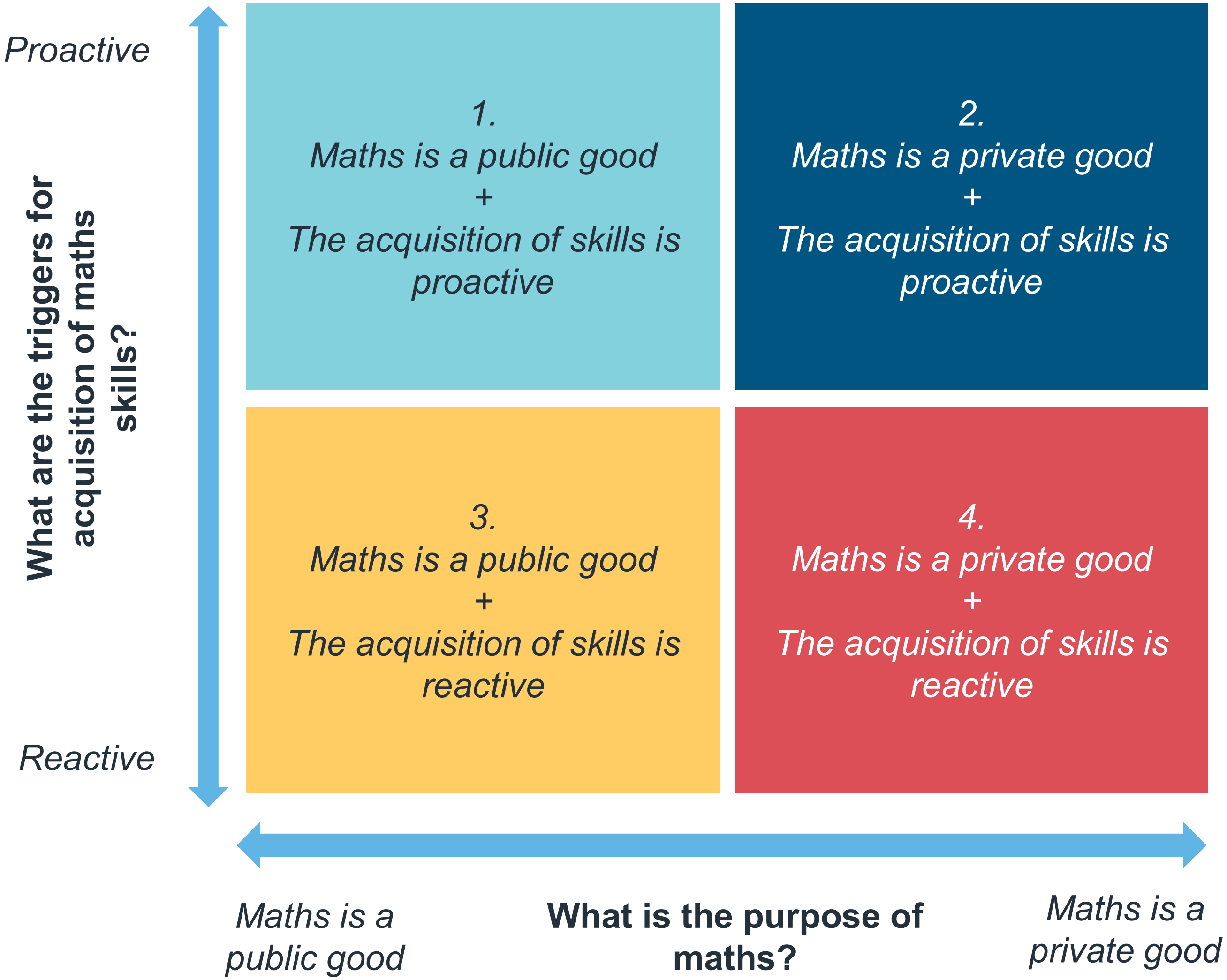
These are not the only forces that will shape the future of mathematics. But by taking different combinations of the answers to these questions, we can tell vivid - and divergent - stories about the future. They will help to think about what a future we do want might look like, and what steps we will have to take to get there.

We have identified six questions – or axes of uncertainty - which are likely to drive divergent futures for mathematics

What are the triggers for acquisition of maths skills? The extent to which acquisition of maths skills is driven by an external shock or policy led, driven by government investment in human capital.	Reactive	Proactive
What is the purpose of mathematics? The extent to which the purpose of acquiring maths skills has a social / citizenship focus or an employment / job skills focus – with implications for the kinds of maths skills that are valued.	Maths as a public good	Maths as a private good
How broadly will skills be distributed? Whether maths skills are acquired by a broad base or in narrow pockets across the population.	Broad acquisition of a skills	Narrow / pockets of acquisition
What will the prevailing attitude to mathematics be? The extent maths is perceived to be important to everyday life, with confidence in the execution of those skills.	Positive	Negative
What is technology's role in maths? More mathematically sophisticated technology is a given, but how widely shared are the skills to use that technology? Does user accessibility reach new heights or will the most advanced technologies only be accessible to advanced users?	Tech concentrates on accessibility	Tech concentrates on excellence
What is the relative UK position as a producer of maths skills and knowledge? Leader or laggard?	Leader	Laggard

Scenarios

We have structured the scenarios around two axes of uncertainty



Scenario outline

Proactive

1. A New Consensus: a utopian outcome, but an unclear pathway

- The argument for investing in maths skills is won, both with policymakers and politicians, and among society more generally.
- A policy led, incrementalist, OECD human capital development approach is adopted by the UK. The Government leads progress towards a high growth tech and science knowledge economy.
- Maths skills are broadly and equitably acquired. Machines do most of the work: discovery and relationship-based professions proliferate.
- There are positive attitudes to sharing safely anonymised data – meaning that the benefits of consolidated data (and maths) for health, climate change are broadly felt.

The challenge for this scenario is that the trigger is not obvious: exhortation-led approaches on the importance of maths have not been successful so far, it is unclear what would trigger this change

2. Small Pieces, Loosely Joined: muddling through is business as usual

- Whilst everyone recognised the argument for investment in maths skills, the government does not change the course of maths skills acquisition.
- Employers make most of the investment to compensate, there are islands of competence but there are still lots of problems in terms of skills gaps, critical skills, and functional numeracy.
- The need for maths is operational and transactional; there's a maths person in every team (rather than maths skills being distributed).
- A tech and science- led infrastructure emerges with a different economy on top: relationship- based, caring professions grow. The government picks some winners, resulting in excellence in some sectors of the economy. There are narrow pockets of excellence.

This is a BAU scenario

Maths as public good

Maths as private good

3. Emergency Response: necessity is the mother of invention

- An existential threat – perhaps a cyber war, a climate change trigger – acts as an external trigger that requires citizens to gain maths skills, and quickly - in the same way that the pandemic taught the population about R numbers.
- Although the drivers are external, social solidarity is high. Mass communication efforts educate and protect people.
- The overall pace of advanced mathematical discoveries increases, driven by investment in response to the crisis (equivalent to Enigma/Manhattan project style investment) leading to constructive innovation with broad benefits in the long term, based on the contribution of a reasonably small number of advanced users.

This is a conflict-driven scenario: it will be harder to convince policy stakeholders to invest now (cf pandemic, anti-microbial resistance)

4. National Drift: relative decline and private benefit

- The UK drifts and declines, with no leadership from government and growing external threats.
- Unsupported by the government to meet their functional needs – and exploited from more angles (e.g. predatory financial products) – attitudes to and confidence in maths worsen. There is low trust and low social cohesion.
- Unable to meet their skills requirements, companies look to outsourcing and immigration - as much as the need for resilience allows. Acquisition of maths skills is highly unequal.
- Unchallenged, companies reach peak data consolidation, leading to worsening attitudes to data sharing – which affects maths' ability to broadly benefit society.

This is a dystopian scenario

Reactive

Implications of scenarios for RS populations

Scenario	1. Basic everyday numeracy	2. Critical skills	3. Increasingly quantitative professions	4. Maths adjacent professions	5. Advanced mathematicians
1. A New Consensus	Thrives across the population	Steady growth as spillover of functional numeracy, but fewer external threats to respond to	More skilled workers available to enter these professions, fewer skills gaps	Larger talent pool for professions that can address societal challenges	Discovery based work increases
2. Small Pieces, Loosely Joined	People realise the importance of basic skills, but often too late	Low investment here	Islands of excellence emerge	Islands of excellence emerge	Lots of talent drawn into industry and away from academia
3. Emergency Response	Some progress in the long term but focus will initially be on critical skills	Adaptive critical thinking skills are well supported	Neutral: some winners where critical skills are important	Positive where they are oriented towards responding to a threat	‘Manhattan project’ teams thrive, create long term value
4. National Drift	Decline, widening achievement, low resources and policy attention	Suspicion of mathematics grows, misinformation rife,	Where possible, skills are filled through outsourcing / skilled immigration	Largely hollowed out, talent is harder to retain	Low priority, top talent exodus

Skills requirement are in deficit, population needs are not met	Neutral, similar to now, mixed	Skills requirements of population are met, skills are valued

Scenario 1

A New Consensus: the case for mathematics is won, but the trigger is unclear

Key events:

The challenge of this scenario is the uncertainty about what might trigger large scale investment – we have chosen one…

- The impact of the pandemic on education starts to manifest, with terrible consequences – young people struggle to function in society or to hold down jobs. Society sees the consequences of disruption to even a few years of education, and demands a fix. Education is the top issue of concern in the next election. The reputation of the UK’s education system is under threat. A new government is swept in, not least on the strength of its renewed commitment to education, and a mandate to overhaul the entire curriculum. A high tech, science-based knowledge economy is the goal, and mathematics at all levels is understood as the foundation to this.
- The private sector and civil society swing into action too, with government subsidies to improve lifelong learning in mathematics.
- Moreover, there is bottom up demand. People can see the benefits of improving their skills – and a virtuous circle starts, people are able to put maths skills to work, the gain more confidence and seek more knowledge. Pursuing mathematical knowledge for its own sake is popular – there are Netflix documentaries on the Banach-Tarski paradox, progress on the Clay Institute challenges make the front pages.
- The market for Ed Tech grows to meet this demand, on demand. Courses are free, every level of ability and domain of interest. Professions have little trouble in becoming more quantitative.

The role of mathematics

- Attitudes to maths are very positive; it is understood to foster the logical and critical skills required for participation in the world, as the core language through which science, commerce and society. It is understood as essential to everyone’s personal and working lives.
- Mathematics’ potential to solve great societal challenges is realised: forecasting climate models, optimising food systems, developing smart city infrastructure, using big data in healthcare to improve diagnosis and develop new treatments. It contributed to better decisions, better collaboration, increase life expectancy.

Key question: This is the desired end-state for many. The benefits are clear but the trigger for investment remains abstract. How was the argument won?

Scenario 1 implications

A New Consensus: the argument is won for OECD-type human capital investment leading to broad skills acquisition and shared benefits of maths - but the trigger is unclear

Description

Frame	Description
The education system	There is investment at all levels. Ed tech gets good enough to be able to teach at the point of demand. There is less need to make maths compulsory, the population pursues it anyway. The government recruits internationally for the best maths teachers.
Attitudes to maths	Maths is viewed positively, people feel the benefits. Inspirational aspects of maths are independently pursued.
Relative position of the UK	UK is a leader, measure by investment in maths education. It is at the forefront of mathematics being applied to global society challenges.
Skills gaps, skills in demand	Gaps are low, most people have the essential skills they need in terms of functional numeracy. There are spillover effects into numeracy for critical thinking.
Tech	There is sufficient white space left by tech for there to be a need for maths skills.
Pace of mathematical discoveries	High permeability between academia and maths application; not as fast as the Emergency scenario, less driven by necessity; some areas fulfil promise (e.g. ML, quantum computing).

Prescription

Implications for…	
Maths policy	All the hard work has been done, it needs to be maintained
Types of skills in demand	Broad, both pure and applied

Scenario 2

Small Pieces, Loosely Joined: without policy intervention or leadership, the private sector leads the way and maths skills focus on jobs and employability

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Key events

- Pressure on public spending keeps policymakers largely on the side lines. Political focus is on cost of living, fragmentation of the global order and recovery from the pandemic. Education policy is not in the spotlight. Everyone agrees that mathematical education is important, but there is little scope to make more than incremental improvements - which are oriented towards employability. The private sector is in the best position to lobby for improvement. Government efforts are based on relatively low-cost interventions to exhort entrance to maths/maths adjacent professions and courses (exhortation-led, diversity focussed public information. Maths stays compulsory, and becomes a required element for many other courses, but without investment to upskill teachers, the quality is varied.
- The private sector steps in to fulfil its needs. Competition for maths/maths adjacent graduates is fierce. Maths prizes grow. The private sector subsidises university courses and concentrates on industry placements. Universities sell their courses based on exposure to 'real world' industry problems, with maths undergraduates taking placements in Amazon logistics divisions. Programming is an essential part of quantitative degrees.
- Islands of excellence centred around tech emerge, with some government support: in fintech, cyber security, AI. These are city-based and regional.

The role of mathematics

- Maths skills are oriented around jobs and employability: maths talent is drawn to questions related to commerce such as optimising business analytics, managing productivity and supply chains,
- Maths skills are concentrated on working with tech – translation of real-world problems into mathematical problems that can be solved in 'black boxes' – so skills around translation, interpretation, error checking are highly valued
- Top talent is drawn away from application of mathematics for societal challenges.
- Discovery / advanced mathematics is slowed in western economies as talent is drawn away

Key question: How do you make the whole greater than the sum of its parts?

Slide 9

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Catherine Boulton, 2023-08-23T15:34:29.159

Scenario 2 implications

Small Pieces, Loosely Joined: without policy intervention or leadership, the private sector leads the way, and maths skills focus on jobs and employability

Description

Frame	Description
The education system	There is little leadership from government – everyone does their own thing, for their own purposes. The curriculum is mostly unchanged, but private actors have taken their own steps to fill their requirements (workforce investment – or outsourcing, immigration). GCSEs remain compulsory as there is to give the population maths skills before they realise they need them.
Attitudes to maths	Widening gulf between general population (attitudes are negative/like today - until people realise how important they are for jobs) and more expert groups.
Relative position of the UK	The UK is strong in some applied areas of mathematics (finance, cyber security).
Skills gaps, skills in demand	There is fierce competition for a few winning sectors, well off employers are unaffected, but gaps in industry
Tech	Tech takes care of most of the mathematics – a relatively small number of people employed in translation and interpretation of maths skills into black boxes.
Pace of mathematical discoveries	Talent battle leads exodus of advanced mathematicians from discovery work into more lucrative islands of competence.

Prescription

Implications for…	
Maths policy	Need to give people maths skills before they realise they need them – longer compulsory. Need to make maths more attractive.
Types of skills in demand	Transactional, specific to industries – concentration on operational execution.

Scenario 3

Emergency Response: an existential threat triggers the need to rapidly expand maths skills in the population

Key events: upskilling the population with critical and computational skills is the key to surviving an existential societal challenge

- After decades of digitisation, the rug is pulled from under everyone's feet as swathes of digital systems – banking, commerce, communications, national infrastructure – collapse almost overnight from coordinated, sophisticated cyber attacks.
- The initial response is panic. It feels like the early days of the pandemic, but worse, as the problem is all too visible. People can't get into their bank accounts, transport systems are temperamental, internet access is patchy. The early weeks are focussed on fixing national infrastructure. In addition to calling on national resources, the Government mobilises private sector experts to fix broken systems.
- There is a huge overall loss of trust in society. Misinformation is rife, with wild theories about the source of the attacks. People can't even be sure that messages from family members are real. Government and Big Tech mobilise fix and patches, with mixed success – improving IT skills and UX alone is not enough, many are still exploited.
- It becomes apparent that there is a need to equip the population in general with skills in mathematical thinking to rebuild this trust: in the same way that R numbers were taught in the pandemic, this new crisis requires the population think more critically and to understand mathematical concepts like zero knowledge proofs to rebuild trust. These skills are seen as vital for getting through everyday life.
- The government invests in 'Manhattan project' type initiatives to protect the population and national infrastructure – and ensure that this can never happen again. GCHQ and top university maths departments see big investment, and the UK becomes a global leader in cryptography and its applications in building trust in the virtual world. The long-term spillover benefits are huge: the UK is a hub for cryptography and cyber security

The role of mathematics: defending the population

- Mathematical thinking and computational thinking are the best vaccination for protecting the general population from exploits. Success depends on not just giving instructions to implement fixes – it is also dependent on simultaneously investing in mathematical thinking to be effective and rebuild trust that systems are secure. Government and Ed Tech combine to produce critical / computational thinking resources.
- At the advanced end: cryptography (linear algebra, combinatorics, statistics, number theory) draws talent with big investment.

Key question: How do you prepare for a crisis? What skills and knowledge do you distribute? How?

Scenario 3 implications

Emergency Response: triggered by an external threat there is a ‘wartime effort’ to equip the population with maths skills

Description

Frame	Description
The education system	Government-led mass communication efforts to educate people to solve immediate problems. Self service at first, patchy response, but contingent resources are deployed over 2-3 years. Government buys private sector Ed Tech to build critical capabilities in the general population. Resources are poured into higher education to build (Bletchley Park) defensive projects. As problem recedes, infrastructure takes over
Attitudes to maths	Maths is seen as instrumental, key to getting through everyday life. There are some denialists.
Relative position of the UK	As this is likely a global moment, the diversity of UK outcomes is wide; with a strong response the UK might come out with a relatively good position.
Skills gaps, skills in demand	In some sectors there are big initial skills gaps – as talent is drawn to fixing the trigger. The skills depend somewhat on the threat – it could be understanding volatility, or cryptography.
Tech	In the long term, big benefits to ’wartime’ investment in innovation; in the short term, defensive tech (and defensive ed tech) is in high demand.
Pace of mathematical discoveries	High – in response to the crisis, big investment to solve societal challenge (radar for carbon storage) leads to huge benefits in the long term: highly skilled individuals, successful tech

Prescription

Implications for…	
Maths policy	Needs to focus on a broader set of topics for resilience.
Skills in demand	Depends on the threat: Understanding of volatility, cryptography likely important.

Scenario 4

National Drift: no leadership from government and growing external threats make many in the population vulnerable

Key events

- Crises – across food systems, energy systems, climate systems, trade – overwhelm the capacity of the government. Public life becomes increasingly chaotic, national politics lurches from crisis to crisis. Education is a low priority and decline feels inevitable. Class sizes get bigger, attainment decreases, teaching is under-invested.
- Bad actors – influencers selling predatory crypto products, misinformation peddlers – prey on the vulnerable. People invest their life savings in get-rich-quick crypto products to find they have been swindled. These actors have a substantial section of the population to target: a growing proportion are leaving education without necessary critical and computational thinking skills. There is low trust and low social cohesion. Governments try to intervene through public information but this often comes too late, and they lack the resources to properly address the exploiters.
- The population in general views maths with suspicion– no one to provide inoculating skills against exploitation.
- Skilled mathematicians move to areas and professions where their skills are more valued, often for benefit of the wealthy global elites: private and personalised cyber security, wealth protection and asset management.
- Companies and industries that require maths skills look to either outsource or skilled immigration to acquire the quantitative skills; they open hubs where maths skills are available (India, Singapore).

The role of mathematics

- The acquisition of maths skills is highly unequal: a wealthy minority are able to access skills but the general population loses out.
- With little challenge from policy makers, peak data consolidation is possible for Big Tech, compounding the perception among the general population that maths is being ‘used against them’ – to predict their behaviours and target them with advertising. As people are less willing to share their data, many of areas where big data can be used to improve societal outcomes (healthcare, infrastructure) are hampered.

Key question: How do you avoid this?

Scenario 4 implications

National Drift: no leadership from government and growing external threats make many in the population vulnerable

Description

Frame	Description
The education system	Drift and decline. Widening achievement. Reactionary / panic reforms do more harm than good. Functional numeracy levels decline.
Attitudes to maths	Suspicious, unequal – maths is used to exploit people but the population doesn't have the skills to avoid this.
Relative position of the UK	UK is a laggard; the reputation of its education system is badly damaged. The best mathematicians look overseas for career opportunities. The UK becomes a net exporter of students.
Skills gaps	Companies look to outsourcing and immigration as much as possible – but hampered by need or resilience, they must maintain a core set of competent people in some centres. Where it is cost effective, the private sector builds some skills domestically.
Tech	Without policy intervention, peak data consolidation occurs. Limited ability to curb the worst excesses of predatory tech. Accessibility of tech is low.
Pace of mathematical discoveries	Slow, driven in pockets by the private sector; low government investment in mathematical excellence, the UK has diminishing advantage from previous era of being at the forefront of mathematical discovery.

Prescription

Implications for…	
Maths policy	Low capacity to influence outcomes
Types of skills in demand	Basic functional skills

We have based this on interviews, scenario planning workshops and our own internal development

Methodology

- Interviews: to identify and prioritise drivers that will shape the future value and importance of mathematics and key uncertainties (18 interviews complete – target: 15)
- 2 scenario planning workshops: to validate drivers identified during interviews, synthesise evidence, explore implications and begin to describe potential future scenarios
- Internal analysis and synthesis: analysis of workshop outputs to identify key axes of uncertainty, testing different combinations of axes, prioritisation of axes to produce a manageable, vivid and stimulating set of scenarios

Organisations represented in interviews and workshops

- Private sector: Jaguar Land Rover, Astra Zeneca, Kantar Media, Rolls Royce, Canary Wharf Group, Healx, The Care Machine, Man Group
- Learned Societies: Royal Statistical Society, Royal Society of Engineering
- Higher education and research: Imperial College, University College London, Oxford Centre for Industrial and Applies Mathematics, University of Derby, Eindhoven University of Technology
- Government / public bodies: Office for National Statistics, European Molecular Biology Lab, Association of Colleges, National Numeracy

What a good set of scenarios should look like

Good scenarios should be a rallying flag to promote constructive, action-oriented discussion among stakeholders, with a sense of urgency on what is at stake, challenging policymakers to think more ambitiously:

- **Accessible** → e.g. 3-6 scenarios in total, potentially constructed as a 2x2 matrix
- **Vivid** → e.g. evocative, memorable names; represent archetypes (a stylised depiction that draws out distinctive elements)
- **Relevant** → e.g. internally coherent, believable outcomes; a kernel of each scenario visible in society today, but uncertain over which might dominate
- **Broad** → cover a broad range of likely outcomes, noting wildcards relevant to each scenario (out-of-scope wildcards to be identified separately)
- **Actionable** → e.g. imply options for skills-sector policies (defined broadly), with differences/overlap between scenarios + early warning signs