Australian Government
Chief Scientist

SCIENCE, TECHNOLOGY, ENGINEERING AND MATHEMATICS: AUSTRALIA'S FUTURE

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AN AGENDA FOR CHANGE

This paper builds on the Chief Scientist's position paper, *Science, Technology, Engineering and Mathematics in the National Interest: A Strategic Approach*, calling for a whole of government approach to investment in STEM.* Following its public release in July 2013, the position paper received broad support across the research and business sectors. The Business Council of Australia's *Action Plan for Enduring Prosperity* endorsed the approach and recommended its swift adoption.

The Chief Scientist here puts forward a strategic approach to STEM as a recommendation to government.

* STEM is an acronym for science, technology, engineering and mathematics. For an overview of STEM, see Appendix 1: Scope of STEM.

CONTENTS

FACING UP TO THE TASK

The reality is that we can't relax. We can't be complacent. There can be no sense of entitlement. We must understand that we will get the future we earn.

– *Science, Technology, Engineering and Mathematics in the National Interest: A Strategic Approach* (July 2013)

The global economy is changing. New technologies and smart companies lead. New industries and new sources of wealth are emerging. New skills are required for workers at all levels.

Australians must decide whether we will be in the forefront of these changes or be left behind. We have a choice.

Our competitiveness cannot be underpinned by our natural resources alone.

Nor can we afford to be complacent about our place in the global race.

Nations at all levels of development are now focusing on the capabilities required for building new jobs and creating wealth. In partnership with business, they are acting now to secure the skills, investment and international alliances for the future.

At the core of almost every agenda is a focus on STEM: science, technology, engineering and mathematics. It is the almost universal preoccupation now shaping economic plans. In other words, the economic plans are designed to support the focus on STEM, rather than limit it.

We too need to recognise that prosperity has to be earned; just as opportunity must be embraced.

Above all, we need to ensure that our needs and our capabilities are aligned: across government and across the Australian community.

It is the knowledge that STEM will offer and the sensible application of that knowledge that are the means to the end: building a stronger Australia with a competitive economy.

> *There will be significant emphasis in boosting our focus on science, technology, engineering and maths because science is at the heart of a country's competitiveness and it is important that we do not neglect science as we look at the general educational and training schemes.*
>
> – Prime Minster of Australia, the Hon Tony Abbott MP (June 2014)

THE ENDS AND MEANS

The end we aim to achieve is to build a stronger Australia with a competitive economy. We will need to facilitate growth in ways and on a scale that we have never achieved before. It is time to do what so many other countries have already done: take a long-term strategic view of STEM's pivotal role in securing a stronger Australia.

THE MEANS TO THE END:

Australian competitiveness

STEM underpins a differentiated and readily adaptable economy that is globally competitive and will enable all Australians to benefit from the opportunities that follow.

Education and training

Australian education—formal and informal—will prepare a skilled and dynamic STEM workforce and lay the foundations for lifelong STEM literacy in the community.

Research

Australian STEM research will contribute knowledge to a world that relies on a continuous flow of new ideas and their application.

International engagement

Australian STEM will position Australia as a respected, important and able partner in a changing world, for both domestic and global benefit.

WHY STEM?

Science and innovation are recognised internationally as key for boosting productivity, creating more and better jobs, enhancing competitiveness and growing an economy.

It is estimated, for example, that scientific and technological advances have produced roughly half of all US economic growth in the last 50 years.

In Australia, 65 per cent of economic growth per capita from 1964 to 2005 can be ascribed to improvements in our use of capital, labour and technological innovation—made possible in large part by STEM.

International evidence shows that:

- increases in research and development (R&D) substantially boost per capita growth
- publicly-funded R&D has a high rate of return, and drives economy wide productivity growth
- private R&D delivers high returns to individual firms, which flows on to workers and communities.

STEM skills are critical to the management and success of R&D projects as well as the day-to-day operations of competitive firms.

They are the lifeblood of emerging knowledge-based industries—such as biotechnology, information and communications technology (ICT) and advanced manufacturing—and provide competitive advantage to established industries—such as agriculture, resources and healthcare.

Strong performance in STEM is also critical to our education sector—now Australia's fourth largest export industry.

An education in STEM also fosters a range of generic and quantitative skills and ways of thinking that enable individuals to see and grasp opportunities. These capabilities—including deep knowledge of a subject, creativity, problem solving, critical thinking and communication skills—are relevant to an increasingly wide range of occupations. They will be part of the foundation of adaptive and nimble workplaces of the future.

Australian firms that actively embrace change as a normal part of business are around twice as likely to use engineering skills, twice as likely to use science and research skills, and three times more likely to use ICT skills.

> International research indicates that 75 per cent of the fastest growing occupations now require STEM skills and knowledge.

The demand for STEM will only continue to grow as we compete in the emerging global economy.

STEM IN CONTEXT

STEM plays a critical role in our economy. But the value of our investment in STEM will be diminished if our practitioners operate without due regard for Australians, and their wants, needs, aspirations and concerns.

STEM must therefore relate to valuable work in the social sciences and humanities. These disciplines are critical to our understanding and recording of our world: our cultures, our knowledge of society and the relationships within society.

Work in the social sciences and humanities is vital to our deep understanding of the social context. Their contribution will contribute to a creative and innovative Australia. It is this context that will influence the extent to which STEM can be effective.

While the focus of this document will be STEM, it will be Australia's STEM working for and with the community, connected by trust and mutual obligation.

TOO IMPORTANT TO LEAVE TO CHANCE

Competing in the new global economy will demand bright ideas and inspired business leadership. It will also require systems that can generate and harness these assets more reliably, and far more often, than Australia has witnessed to date.

For example, there is much to learn from the tools developed by the United Kingdom's Technology Strategy Board (TSB) to concentrate effort and support on areas most likely to generate economic growth and respond to global opportunities. A single body, focused on driving innovation excellence, can achieve results otherwise impossible when activities and responsibilities are split.

Likewise, the longstanding success in the United States of the Small Business Innovation Research (SBIR) programme has informed similar initiatives across the globe.

SBIR harnesses the R&D budgets of federal agencies to foster new and cost-effective technologies with strong commercial potential—making the US Government the biggest venture capital funder in the world.

By-and-large, governments have found that rather than seeking to mandate conditions, they can and do help to create environments in which business, researchers and educators are able to perform at their best—in a cooperative and coordinated way.

There is the lesson for us: top-performing STEM economies are united not by their size or geography but by their capacity to organise then grasp their opportunities.

The evidence shows that high performing countries are characterised by:

- a strong basic or 'blue-sky' research enterprise providing a wellspring of technical know-how and step-change ideas
- rich and deep connections to the global science enterprise
- a culture of risk—assessing it, managing it and taking it
- openness to new ideas
- career pathways from academia to industry and vice versa
- a reliable pipeline of STEM graduates whose skills employers value
- a STEM-literate population that celebrates discovery and entrepreneurship.

TOO LONG LEFT TO CHANCE

Australia is now the only country in the OECD not to have a current national strategy that bears on science and/or technology and/or innovation.

In our region, India, China, Indonesia and Singapore all have strategies to 2015 or beyond.

Australia's STEM investments and policies have suffered from a lack of coordination, misdirected effort, instability and duplication. We have long presumed that good things will just happen if we wait.

At the federal level, policy and programme responsibility is diffuse. The science, research and innovation investment reported in 2012-13—amounting to approximately $8.6 billion—was spread across a suite of programmes in 13 separate portfolios.

State and territory governments all design and fund a patchwork of programmes relevant to STEM—from schools through to vocational and tertiary institutions, and in business and industry. They may, or may not, align with the effort of federal investment in education, innovation or research and development.

Some of these measures are united under shared strategic goals, but many are not. Nor are the goals of specific programmes necessarily clear to the participants or prospective private sector partners.

A result? Australia now ranks 81st as a converter of raw innovation capability into the outputs business needs: new knowledge, better products, creative industries and growing wealth.

> The evidence is mounting that Australia is paying the price and falling behind its overseas competitors on key performance measures.

WE LACK THE BUSINESS — STEM ENGAGEMENT TO GET GOOD IDEAS TO MARKET

Analyses from the OECD and the Australian Bureau of Statistics (ABS) using 2010-11 data highlight Australia's poor record in business to research collaboration.

Using OECD analysis of innovation active businesses, out of a total of 33 countries, Australia ranks 32nd on business to research collaboration for small to medium enterprises (SMEs), and 33rd for large firms.

Similar analysis by the ABS for all OECD countries, but including businesses with 0-9 employees, improves our position to 15th for SMEs and 21st for large firms.

Only 13.7 per cent of our large firms collaborated with research organisations: slightly above the level of collaboration—9.6 per cent—by our SMEs.

WE HAVE A CULTURE OF RISK AVERSION AND INWARD FOCUS

Less than one in two Australian firms identify themselves as innovators.

Just 1.5 per cent of Australian firms developed new to the world innovations in 2011, compared with 10 to 40 per cent in other OECD countries. More than 60 per cent of Australian firms kept innovations within the company.

WE ARE STILL BUILDING RECOGNITION AND RESPECT FOR RESEARCHERS WORKING IN BUSINESS

Less than one in three (30 per cent) Australian researchers work in industry, which is half the OECD average and less than the US, where two in three researchers are in the business sector.

WE HAVE WORRYING GAPS IN THE STEM SKILLS PIPELINE, FROM PRIMARY TO TERTIARY EDUCATION LEVELS

Australia's performance in mathematical literacy in schools has fallen in absolute and relative terms. Of the countries tested in 2003, only five significantly outperformed Australia in mathematical literacy. By 2012 we were outperformed by 12 countries.

Around 40 per cent of our Year 7 to 10 mathematics classes are taught without a qualified mathematics teacher.

While Australia's absolute performance in school-level scientific literacy has remained unchanged, our relative performance has slipped. Of the countries tested in 2006 and 2012, five significantly outperformed Australia in 2012, whereas only three did in 2006.*

Australian schools also show a decline in the rates of participation in 'science' subjects to the lowest level in 20 years. This has consequences for the general level of science literacy in the community and the future workforce.

Science enrolments in higher education have increased by close to 30 per cent since 2007, although study in key fields such as chemistry, physics and mathematics drops steeply after first year.

WE RISK BEING COMPLACENT ABOUT OUR RESEARCH PERFORMANCE: 'WE PUNCH ABOVE OUR WEIGHT'

Whilst we claim to 'punch above our weight' in research, we do not out-perform the countries with an embedded scientific culture that we might aspire to match such as the Western European democracies, Scandinavia or the US and Canada. We can and should aim higher.

WE ARE STRUGGLING TO RECONCILE OUR RELIANCE ON STEM WITH A WIDESPREAD MISUNDERSTANDING OF HOW SCIENCE WORKS

Just 39 per cent of Australians surveyed recently thought that the benefits of science outweighed the risks.

* The US National Research Council has defined science literacy as: the knowledge and understanding of scientific concepts and processes required for personal decision-making, participation in civic and cultural affairs, and economic productivity

SEIZING THE OPPORTUNITY: A STRATEGIC APPROACH TO STEM

If the end we aim to achieve is a stronger Australia with a competitive economy it will require a strategic focus on:

Australian competitiveness

Education and training

Research

International engagement

Our progress will be underpinned by the strength of the disciplines that comprise science, technology, engineering and mathematics.

All of these pieces have to fit together to maximise the returns on Australia's significant public investment in STEM.

Our individual actions must be:

- aligned to clearly articulated national goals
- focused on priority areas where we have comparative advantage or critical need
- scaled appropriately to achieve far-reaching and enduring change.

This approach will provide a path to the future we need.

Above all, it will allow all Australians to see the impact of our actions today on the shape of the nation tomorrow.

Any approach should be updated every two years to ensure that actions are aligned to goals, and investments are delivering returns.

TAKING RESPONSIBILITY

We have had many reports, inquiries, policies and aspirations, with little progress.

Responsibility for monitoring actions and outcomes of our STEM investment is currently split across levels and portfolios of government. Our datasets are incomplete in coverage and fragmented in their approach. We do not have the tools we require to track our progress, act swiftly on gaps or help stakeholders see their place in the whole.

The roll-out of the Strategy should therefore be supported by a comprehensive statistical database on STEM, including education, training, research, international engagement, competitiveness and the workforce.

Progress against the Strategy will be measured by a periodic STEM Capability Report, building on the indicators used by the Office of the Chief Scientist to benchmark Australia's performance in STEM.

FROM AMBITION TO ACTION

The following pages outline what is required to embed a strategic approach across the four identified fields of STEM in Australia—from classrooms through to laboratories and corporate boardrooms. Just as the fields are linked, the actions proposed are complementary. No part of the pipeline can be neglected.

AUSTRALIAN COMPETITIVENESS

AUSTRALIAN COMPETITIVENESS

OBJECTIVE

STEM underpins a differentiated and readily adaptable economy that is globally competitive and will enable all Australians to benefit from the opportunities that follow.

This will require:

- clear innovation priorities, supported by a solid research foundation
- strong linkages between our business and research sectors to increase the translation of knowledge into new products, processes and services
- a flexible workforce with the entrepreneurial skills to thrive in an environment of rapid technological change
- a regulatory environment that supports collaboration and creativity.

Australia currently has many industry investment and incentive programmes to support an array of R&D activities at national and regional levels. However, after decades of inducement, few firms self-identify as innovators or look to capitalise on opportunities created by STEM. We are still looking to learn how to thrive in a period of rapid change.

Business survival today relies on skilful market experimentation, which involves the acceptance, or at least tolerance, of the risk of failure. Like their best performing counterparts overseas, Australian businesses and individuals must be encouraged and prepared to take on risks intelligently, recognising that mistakes and failures can be an important part in improving future competitiveness and profitability.

Our education, research and business sectors must also be better connected if we are to grow our economy and compete on the world stage.

Global and domestic experience confirms that the risk of innovation can be spread through collaboration. The benefits include increased productivity, profitability and targeted export markets. In particular, collaboration between businesses and research organisations more than triples the likelihood of business productivity growth.

Collaboration also lifts the capacity of Australian SMEs to break into global value chains, at the high-value end where we can compete. Access to these chains opens new markets, encourages investment in Australian R&D, and keeps local firms engaged with global technology trends.

We need to look together to the global horizon—starting with the incentives and barriers that governments create. For example, intellectual property (IP) negotiations remain a major obstacle in potential industry partnerships.

The rewards and signals for researchers need to be adjusted to reflect their role on the front-line of Australia's economy. Our systems should focus a substantial part (not all) of our research effort on real national goals, whilst encouraging industry engagement and rewarding both excellence and impact.

Government in turn must build the capability to think across portfolio walls and learn when to let industry take the lead. A single agency—such as the proposed Australian Innovation Board—would coordinate and drive effort. It would frame the big picture for Australia, and support it.

CASE STUDY: US SMALL BUSINESS INNOVATION RESEARCH (SBIR) PROGRAMME

Between 20 and 25 per cent of all funds for early-stage technology development in the US come from the federal government. SBIR makes up 85 per cent of this government spend.

The programme was established in 1982 to maximise the economic returns on publicly funded research. It targets the entrepreneurial sector, recognising that innovation thrives in smaller, more nimble firms.

Each year, federal agencies with external R&D budgets in excess of US$100 million are required to set aside 2.8 per cent of the available funds for SBIR schemes. SMEs can then submit project proposals for needs identified by the agencies, in the context of the explicit research priorities of the US government—such as 'Devices, products, services or technology that would assist the elderly and their families or caregivers during disasters and recovery from disasters.'

For every day the SBIR has operated, seven patents have been granted to participants. The programme has supported 15,000 firms, channelled US$21 billion to priority research goals, and harnessed the skills of some 400,000 scientists and engineers.

Similar initiatives have been established across the OECD.

CASE STUDY: UK TECHNOLOGY STRATEGY BOARD (TSB)

The TSB is the UK's innovation agency and primary channel for accelerating business-led innovation. It designs and delivers a dynamic suite of programmes, recognising that nimbleness and adaptability are critical to its commercial partners. Together, the programmes seek to reconfigure national challenges—such as an ageing population—as opportunities for ambitious firms.

TSB focuses its effort by analysing markets, research capabilities and government priorities, in consultation with all stakeholders. It then develops a 'roadmap' of the requirements to success, and 'maps' the possible interventions to overcome the obstacles to growth. Programmes are designed and evaluated for their alignment with the bigger goal.

For each pound invested by the TSB in collaborative R&D grants, an estimated seven pounds are returned to the UK in the form of increased gross value add.

RECOMMENDATIONS AUSTRALIAN COMPETITIVENESS

It is recommended that the Australian Government:

Establish an Australian Innovation Board to draw together existing Australian programmes and target research and innovation effort to:

- identify innovation priorities and support them with an earmarked portion of overall funding
- solicit and fund research projects that are relevant to the innovation priorities
- ensure adequate support for public sector research that supports innovation priorities
- design and deliver new models for collaboration for maximum impact (for example, the UK's Catapult Centres and Knowledge Transfer Partnerships)
- support local companies with the capacity to take new products and services to the global market
- bring coherence and shared focus to the suite of programmes that presently support innovation.

Support the translation and commercialisation of STEM discoveries through:

- readily accessible mechanisms for industry to link to STEM, including services in the Entrepreneurs' Infrastructure Programme
- translation-specific initiatives, particularly in areas of Australia's innovation priorities
- stronger incentives for SMEs to commercialise discoveries and enter global supply chains
- a national scheme to foster growth in Australian SMEs, drawing on the US SBIR programme
- a modern and flexible IP framework that embraces a range of capabilities from open access regimes to smart and agile use of patent and technology transfer strategies.

Accelerate the integration of STEM experts into industry, business and public sectors through:

- business assistance programmes that facilitate awareness of and use of STEM capability
- including commercialisation skills in research training programmes
- mobility programmes across business, research and public sectors that are recognised by research funding bodies
- better incentives for researchers to be actively involved with industry.

Promote an entrepreneurial culture by:

- supporting entrepreneurship courses in higher education institutions
- facilitating access to novel sources of equity funding, including crowd funding
- integrating innovation and entrepreneurship into mainstream school curricula and assessment
- promoting business innovators and research entrepreneurs as national role models.

EDUCATION AND TRAINING

EDUCATION AND TRAINING

OBJECTIVE

Australian education, formal and informal*, will prepare a skilled and dynamic STEM workforce, and lay the foundations for lifelong STEM literacy in the community.

This will require:

A Secure Pipeline

- recognition of the public benefits that a STEM education brings to the community and to the individual.

Inspirational Teaching

- strong STEM teaching at all levels, supported by high quality and relevant teacher training and subject-specific professional development
- increased numbers of subject-qualified STEM teachers in Australian schools.

Inspired Learning

- a core STEM education for all students—encompassing inspirational teaching, inquiry-based learning and critical thinking—placing science literacy alongside numeracy and language proficiency as a priority
- flexible sequences of study within and between education and training sectors that lift STEM participation and make it possible to master STEM and non-STEM disciplines together
- lifting then maintaining enrolments for core STEM disciplines at the senior secondary and post-secondary levels.

Skilled Workforce

- a high level of STEM literacy across the workforce, in addition to a reliable pipeline of specialist STEM skills and practitioners
- high levels of participation and success in STEM for all Australians, including women, Indigenous students, and students from disadvantaged and marginalised backgrounds
- consideration of the demand side of the Australian workforce.

Engaged Community

- widely accessible opportunities for all Australians to explore, participate in and celebrate STEM.

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* Formal education refers to learning through education institutions with structured and direct instruction, such as schools, universities and though other accredited training programmes. Informal education refers to learning through indirect means such as on-the-job training; through community education centres such as museums, libraries and technology centres; and through the media.

Successful innovation rests on a foundation of education and skills that are relevant to the emerging economic environment, with the capacity to change it.

We need a reliable pipeline of specialist STEM skills; but we also need informed workers, users and consumers who have the curiosity and imagination to be part of the broader STEM economy. This must be underpinned by lifetime engagement for all Australians with STEM, beginning in childhood and constantly renewed as knowledge and technologies expand.

> Our economic growth cannot be sustained without a community of curious and capable people.

Australia's STEM teachers at all levels, from primary to tertiary, must be equipped to deliver course content with confidence and inspiration, and develop all students to their full potential. Curricula and assessment criteria should prioritise curiosity-driven and problem-based learning of STEM—STEM as it is practised—alongside the subject-specific knowledge that STEM requires.

The education system must ensure that students not only acquire knowledge, but also learn how to apply and adapt this knowledge to a variety of contexts.

Students must have clear pathways from the classroom to a career in the STEM economy. Our needs and our capabilities must align.

Australia has limited statistics and information on the development and placement of STEM graduates into the workforce, their integration into the economy, and the projected demand for STEM-skilled employees. Without this knowledge, Australia lacks sufficient understanding of what the economy needs from the education system.

We do know that there is now a shortage of qualified science, mathematics and information and communications technology teachers, and the participation rates of Australian school and tertiary students in STEM disciplines remain a matter of concern.

Too few high-performing STEM students aspire to teaching careers—and too many of our graduating teachers bypassed STEM altogether. Teaching 'out of field' is the new norm.

The performance of Australian school students in science and mathematics literacy is now lower than important international peers. The success of our top performers cannot conceal the gap in the achievement levels of students from Indigenous and disadvantaged backgrounds compared with those from more affluent families.

Women also continue to leave STEM in unacceptably high numbers at secondary, tertiary and early-career level. The proportion of women employed in STEM fields in Australia, while not consistent across all disciplines, is low.

We are locked in a cycle of disengagement that fails our teachers and students today—and puts business at risk into the future. The Australian Industry Group and the Business Council of Australia are now calling for action to prepare more work-ready STEM graduates, from all social backgrounds, to deepen our talent pool and lift national economic growth. They accept in turn an obligation on the part of the business community to show leadership; just as individuals have an obligation to discover and work to their own potential.

Breaking the current cycle will only be possible through business acting in concert with communities, government and educators. Together we must draw on the best international models to support our teachers, inspire our students, and open participation in the STEM economy to all Australians.

> It is recognised that strategies relating to school teaching, curricula and assessment will require negotiations between federal, state and territory governments.

CASE STUDY: STEM EDUCATION AS A US PRIORITY

In the 2011 State of the Union address, President Obama announced the goal of preparing 100,000 excellent STEM teachers over the next decade.

The target formed one of five ambitious commitments in the *Federal STEM Five Year Strategic Plan*, which brings together and bolsters STEM initiatives across portfolios. The Plan acts across the pipeline from schools to the workforce, with actions linked to milestones and performance measures. It emphasises industry engagement and practical pathways into work.

A signature initiative of the Plan is *100Kin10*, a coalition of corporate and philanthropic organisations answering the President's STEM teacher challenge. Members of the 150-strong coalition have raised over US$30 million, while championing STEM teachers in their communities.

CASE STUDY: PRIMARYCONNECTIONS

PrimaryConnections: Linking science with literacy is a home-grown science education initiative built on global best practice. It engages students through hands-on classroom activity, helping them to frame problems, grapple with new concepts, and apply their newfound insights to the broader world around them. This inquiry-based approach is supported by award winning curriculum materials and extensive professional development for teachers.

As programme developer, the Australian Academy of Science is uniquely placed to ensure that student experiences reflect science as it is practised.

The programme aligns fully with the Australian curriculum: science, while supporting key strands of the mathematics and English curricula.

RECOMMENDATIONS EDUCATION AND TRAINING

It is recommended that the Australian Government:

A SECURE PIPELINE

Support the national interest by maintaining the pipeline of STEM graduates, and increase the recognition of STEM education and careers as a public good through:

- mechanisms to encourage student uptake into STEM courses, with particular regard to presently less popular core STEM courses and subjects
- career advice for students that explains the value of study in the core STEM disciplines and the pathways to work it opens, not only in STEM-related fields
- active participation of employers in positioning Australian STEM to be a key to future prosperity
- establishing a framework to design and evaluate school-university partnership programmes.

INSPIRATIONAL TEACHING

Lift the number of qualified STEM teachers by:

- increasing the attractiveness of STEM teaching careers, including the promotion, remuneration and support available to teachers
- ensuring that pre-service training for teachers reflects demand for STEM teachers
- creating incentives for high-achieving STEM students to enrol in teacher training.

Provide all pre-service and in-service STEM teachers with training and professional development opportunities to deliver contemporary science using contemporary pedagogy, with a focus on creativity and inquiry-based learning—more like science is practised.

Ensure active scientists, technologists, engineers and mathematicians are involved in the delivery of content in pre-service STEM teacher education courses at university.

INSPIRED LEARNING

Develop science literacy in schools by:

- ensuring every primary school has at least one teacher with specialist STEM skills
- mandating study of the scientific method, the philosophy of science and the history of scientific discovery
- helping schools to teach STEM as it is practised, in ways that engage students, encourage curiosity and reflection, and link classroom topics to the 'real-world.'

Use curricula and assessment criteria, from primary to tertiary levels, to promote the development of long-lasting skills—including quantitative skills, critical thinking, creativity, and behavioural and social skills—in parallel with disciplinary knowledge.

Ensure that changes to the Australian Curriculum do not diminish the place of STEM.

SKILLED WORKFORCE

Ensure that the skills of STEM graduates are aligned with workforce needs through:

- fostering partnerships between schools, higher education institutions, training providers and employers
- using the partnerships to identify required STEM capabilities
- identifying the mutual responsibilities of industry and government in addressing supply and demand gaps
- commencing a review to ensure that STEM students are equipped to work across all sectors of the economy
- working with educators to identify how required skills can be built into school and post-secondary courses

- promoting inquiry-based STEM teaching in vocational education through the Vocational Education and Training (VET) reform agenda, in consultation with states and territories
- supporting STEM professional development opportunities for members of the workforce to maintain and to broaden skills and focus.

Increase the uptake of STEM across the workforce through:

- mechanisms that explain the opportunities of STEM engagement to business and encourage employment of STEM practitioners
- supporting the widespread adoption of work-integrated learning models, including:
    - exchanges between business and research organisations
    - incentives for education institutions to include work placements for credit in most degrees and training programmes.
- targeted support to increase the STEM participation of women, disadvantaged and marginalised students, including Indigenous students.

ENGAGED COMMUNITY

Facilitate community engagement with STEM through:

- initiatives that increase public interest and involvement in STEM on a national scale
- new and expanded community science groups and citizen science projects
- promoting parental engagement to nurture children's creativity, alongside fostering an interest and involvement in STEM activities and subjects.

Increase communication between STEM practitioners and the community through:

- support for science media channels
- amended standards for government funded research that ensure the appropriate public communication of research findings
- an online portal that acts as an access point for information about STEM—including new discoveries, current projects, community activities and career advice.

RESEARCH

RESEARCH

OBJECTIVE

Australian STEM research will contribute knowledge to a world that relies on a continuous flow of new ideas and their application.

This will require:

- Australian researchers matching the best of their international peers
- high-calibre, ground-breaking and multidisciplinary research across STEM
- a mobile research workforce that is able to traverse both public and private research sectors
- alignment of a proportion of federal government expenditure to big challenges and strategic research priorities
- research infrastructure that is strategic, collaborative and well planned with stable funding arrangements
- research funding that is long-term and well-targeted, including sustained support for knowledge-generating (or basic) research
- open dissemination of research findings in Australia and beyond.

The Australian STEM research effort is broad, crossing from universities to industries and publicly-funded research agencies. All should be encompassed in a bold research agenda.

STEM practitioners must be supported at a level to ensure that their work is both global in reach and ready to meet Australia's needs. It requires long-term ambitions that provide direction for researchers, certainty for investors, and positive signals for students.

Private investment is critical; however, high upfront costs and uncertain outcomes can deter business support for basic research, large-scale research infrastructure, and new-to-market ideas. Rather than crowd out private activity, government stimulates business investment in R&D largely by supplying the 'patient' capital to researchers that tolerates risk and far horizons.

Our effort cannot be siloed by disciplines, or focused so narrowly that the big opportunities slip by. The community receives optimal returns from STEM investments when the whole spectrum of research—from basic to applied—is fully supported, and when appropriate connections to business are encouraged.

However, investments in research must include a strategic base, with commitment to areas of interest, areas of comparative advantage, and areas of priority. The Australian Government—through the development and promulgation of strategic research priorities—will have the means to invest a proportion of its research support in areas of particular importance.

We must also ensure that all parties can meet their share of obligation attached to public investment. Publicly-funded research outcomes must be recognised as a public good, and also be widely diffused or used commercially in ways that benefit Australians. Researchers should be supported to share data, communicate findings and contribute to the global stock of knowledge.

CASE STUDY: HORIZON 2020

Horizon 2020 is the European Union (EU) Framework Programme for Research and Innovation. At nearly €80 billion, it represents the largest commitment to research and innovation in EU history. The suite of funded programmes will run from 2014 to 2020.

Horizon 2020's Societal Challenges component translates the goals of the Europe 2020 growth strategy into seven core priorities for researchers. In each of the priority areas the European Commission frames specific challenges—with an objective, a budget, and a timeframe for results. Researchers across the EU are invited to submit proposals.

Horizon 2020 also includes measures to help policymakers understand what citizens want; and citizens to understand what research can offer.

CASE STUDY: COOPERATIVE RESEARCH CENTRES (CRCs)

Invasive animals cost Australia at least $740 million per year in lost agricultural production and control costs. The Invasive Animals CRC brings together 27 participants, across four countries, to tackle the problem.

A powerful mix of businesses and researchers work together to develop market-ready solutions; from computer-assisted pest detection systems to new and better pesticides. The work is informed by world-leading expertise in ecology, bio-control, environmental genomics, analytics and new toxin development.

STEM capabilities are coupled with expertise in the social sciences, ensuring that research priorities evolve in tandem with community needs.

In addition to the value to Australian agriculture—in excess of $1billion—the CRC generates a constant stream of new products with global market potential.

RECOMMENDATIONS RESEARCH

It is recommended that the Australian Government:

Adopt a long term plan for science and research that will:

- ensure capability in the core sciences and maintain key components of basic research—the continuous flow of new knowledge
- support excellent research that provides new ideas and new insights that will enhance Australian competitiveness
- cover the full direct and indirect costs of research
- enable strategic investment in research infrastructure
- provide stability and direction for both research institutions and businesses.

Develop and implement strategic research priorities that:

- support Australia's needs and draw on our comparative advantages
- complement priorities for innovation
- are reviewed periodically to ensure they remain aligned with challenges confronting Australia.

Support research careers, including collaboration with industry and business, by:

- providing stable, continuing support programmes for postgraduate, early and mid-career researchers
- reforming researcher recognition to value collaboration with industry and business where academic publications are not the primary focus.

Enhance dissemination of Australian STEM research by expanding open access policies and improving the supporting infrastructure.

Provide support to encourage and enable quality research to respond to problems identified by industry.

INTERNATIONAL ENGAGEMENT

INTERNATIONAL ENGAGEMENT

OBJECTIVE

Australian STEM will position Australia as a respected, important and able partner in a changing world, for both domestic and global benefit.

This will require:

- researchers working to understand the modern world and respond to its complex challenges
- strong international networks and projects that include individual researchers, teams and institutions, and business
- high level alliances in strategically important STEM to address shared global challenges and build mutual capability
- an engagement strategy that harnesses STEM to Australia's advantage
- leadership in the formation of an Asian-Area Research Zone.

STEM is truly global. Knowledge and ideas flow freely across national borders.

We are rightly proud of the STEM researchers and business leaders we have placed on the global stage; but we cannot afford to assume that our place on that stage is secure. It has to be earned through our continued contributions to the global STEM endeavour.

Nor should we pass up the opportunities that our STEM capabilities can open.

STEM can bridge cultural divides through its absence of ideology and shared intellectual tradition. It also showcases Australia's advantages as a destination for international students, R&D investment and business partnerships. Inward investment from multinational companies and access to global supply chains must flow from these relationships.

Businesses and higher education providers are crucial STEM ambassadors. But, effective and informed engagement requires the leadership of the Australian Government. As the custodian of our reputation and the architect of our global agenda, it can position Australians to excel.

Australia has much to gain from partnership with the powerhouse STEM nations of the OECD. We also have a moment of opportunity in Asia.

We must recognise, however, that the competition for partners is fierce—and will only continue to grow. We have to come to the table with something to offer: a strategic fund for STEM engagement.

We should also come with a strategy to shape the STEM agenda, looking particularly to the interests of our region.

A forward-looking plan for an Asian-Area Research Zone would keep Australia at the centre of its rapid economic progress. Like its counterpart in Europe, such an area would encourage researchers, knowledge and technology to circulate freely within and between member states. It would build STEM capability and generate STEM solutions for the challenges we confront together.

CASE STUDY: EUROPEAN RESEARCH AREA (ERA)

The EU has been working towards the common goal of an ERA since 2000, building over time both the mechanisms for collaboration and the links into national agendas. The process has gained renewed impetus in recent years, as nations look to maximise the return on their individual research spend and capture shared opportunities for economic growth.

The objectives of the ERA include optimal transnational cooperation and competition, with common research agendas for grand challenges; EU-wide competition for funding; and collaboration on key research infrastructure.

Enabling mechanisms include a Policy Support Facility to help improve national and regional strategies; funding to excellent research institutions with emerging counterparts; and networks to coordinate information about funding opportunities for EU researchers.

CASE STUDY: SQUARE KILOMETRE ARRAY (SKA)

Located in Australia and South Africa, the SKA is a next-generation radio telescope that will comprise millions of antennas and dishes working together as a single instrument.

The SKA is jointly funded by more than 10 countries and is currently being designed by science institutions and technology companies around the world. Over 100 organisations (including Australian businesses and science organisations) from about 20 countries are involved in this 'preconstruction phase' of the project, producing detailed designs for the various elements of the telescope.

International engagement and collaboration has been, and will continue to be, a key factor in the success of the SKA project. It is a real world example of science working globally, across borders and cultures, to solve some of the fundamental mysteries of the universe. SKA research has already produced spin-off benefits, such as low-electricity cooling systems for supercomputers, which will have global non-science applications.

This unique project is set to test the limits of human engineering and scientific endeavour over the next decade, and Australia is playing a major role in its development.

RECOMMENDATIONS INTERNATIONAL ENGAGEMENT

It is recommended that the Australian Government:

Adopt an international strategy for science, research and education that provides:

- a prioritised approach for international engagements that are funded
- for collaborative activities, excellence-driven institutional and individual collaborations, and business partnerships.

Establish a fund for strong government-to-government linkages as a basis for international collaboration, with a focus on:

- building on existing partnerships with regional countries to establish an Asian Area Research Zone
- further developing STEM relationships with the EU and US
- building similar strategic relationships with countries aimed at mutually beneficial outcomes with enduring legacies.

Unlock flows of knowledge and research talent through:

- international exchanges for postgraduate, early and mid-career researchers
- incentives for top international STEM experts to study, teach, and work on projects of global significance in Australia.

Leverage STEM in international diplomacy by:

- providing a framework for science diplomacy as a tool in Australian diplomacy
- promoting the role of Australia's education and science counsellor network.

APPENDIXES AND DATA SOURCES

APPENDIX 1: SCOPE OF STEM

STEM, or science, technology, engineering and mathematics, refers collectively to a broad field of distinct and complementary approaches to knowledge.

Each has a critical role to play in its own right, but also enables discovery and progress in other fields.
While definitions vary, for the purposes of this document:

- **Science** encompasses disciplines within the natural and physical sciences: astronomy and the earth sciences, physics, chemistry, the materials sciences, biology and biomedical science. These sciences are characterised by systematic observation, critical experimentation, and the rigorous testing of hypotheses.
- **Technology** provides goods and services to satisfy real world needs; operating at the cross-section of science and society. Information and communications technology is playing an ever increasing role in our society and provides enabling capacity to the other STEM disciplines. The output of the technology provided must eventually stand the test of users and the marketplace.
- Similarly, **Engineering** draws on the knowledge and methods of science to address and solve immediate problems; often without the luxury of abundant or complete knowledge and, in addition, taking account of aesthetics, user needs and economic constraints.
- **Mathematics** seeks to understand the world by performing symbolic reasoning and computation on abstract structures and patterns in nature. It unearths relationships among these structures, and captures certain features of the world through the processes of modelling, formal reasoning and computation.

A STEM education does not merely impart content knowledge in these fields—it seeks to provide frameworks in which new problems can be tackled.

STEM graduates cite higher order skills in research, logical thinking and quantitative analysis as the return on their degrees; alongside the qualities of creativity, open-mindedness, independence and objectivity.

APPENDIX 2: STEM OFFICIALS WORKING GROUP

The STEM officials working group was established to provide integrated advice to the Chief Scientist on the development of a STEM Strategy.

Members for the officials working group were drawn from the following areas of the Departments of Industry and Education.

DEPARTMENT OF EDUCATION

- Research and Strategy Group
- Research Funding and Policy
- Research and Higher Education Infrastructure
- International Strategy
- Curriculum and Learning
- Office for Teaching and Learning

DEPARTMENT OF INDUSTRY

- Chief Economist
- Science Policy and Agencies
- Research, Collaboration and International Engagement
- Innovation Policy
- Productivity and Competitiveness
- VET Policy
- Industry Skills
- Enterprise Connect Network
- Manufacturing Policy

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