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Science, Technology, Engineering and Mathematics in the National Interest: A Strategic Approach

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PREAMBLE

Australia invests in education and research for many reasons. But top of the list is the critical role they have in ensuring the continued prosperity of Australia on all fronts – socially, culturally and economically – for all our citizens and for our place in the world.

As we position to meet whatever challenges lie ahead, a vital part of our investment must be in the whole Science, Technology, Engineering and Mathematics (STEM) enterprise – all levels of STEM education and research.

Education in STEM must provide Australia with both expert practitioners and a knowledgeable and receptive community.

Research in STEM must ensure a steady flow of new ideas and knowledge. Innovation must turn knowledge into new and better ways of doing things for the benefit of all Australians, and for humanity at large using the global connections that are intrinsic to quality STEM.

But the value of the investment in STEM will be diminished if practitioners operate without due regard for society and its wants, needs, aspirations and concerns.

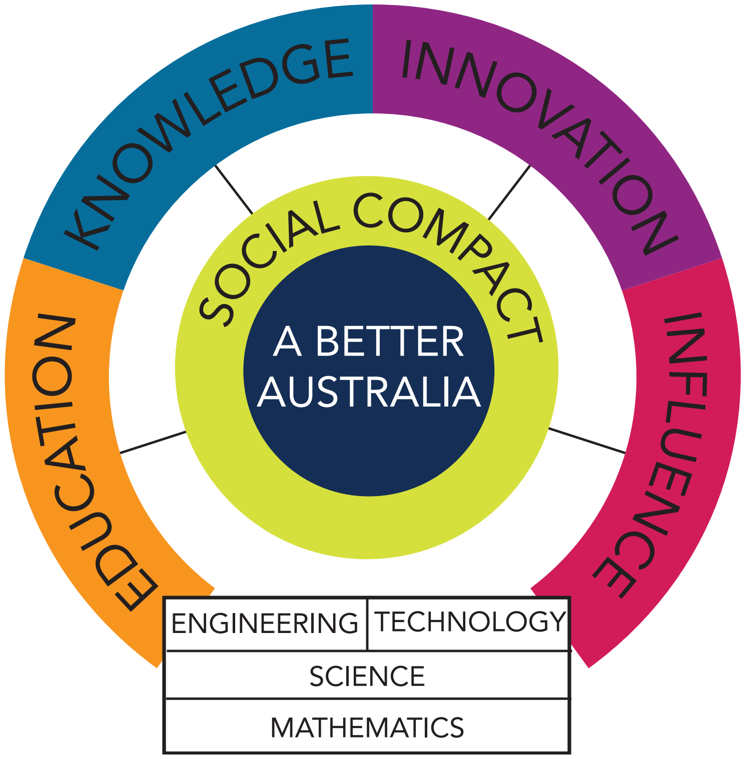
The investment in STEM education and research must therefore relate to valuable work in the social sciences and humanities, both of which are critical to our understanding and recording of our world, our cultures, our knowledge of society and relationships within society.

> *The benefits of science will only be exploited through a renewed compact between science and society, based on a proper understanding of what science is trying to achieve.* [1]

Work in the social sciences and humanities is vital to our deep understanding of the societal context. And it is that context that will influence the extent to which STEM can be effective. While the focus of this Strategy will be STEM, it will be Australia's STEM enterprise operating with a 'social licence' that is a part of its 'compact' with society.

This Strategy is directed to the Australian Government. This is because it is the approach of the Australian Government and its expenditure profile that will have the most significant impact on STEM in Australia. It is important, however, that the States and Territories are consulted about relevant matters as policies and programs are developed. The pay-off will be greater if some proportion of State and Territory investments are aligned with that of the federal government.

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.



This diagram depicts the Strategy. It highlights the primary purpose of STEM in our community – the reason for doing things – to achieve **A Better Australia**, by addressing clearly articulated goals – in particular, the societal challenges we face.

It is a strategy with four essential, interconnected elements:

- **Education**: formal and informal;
- **Knowledge**: ensuring a continuous flow of new ideas, and their dissemination;
- **Innovation**: using knowledge to produce high value goods and services;
- **Influence**: collaboration, networks and alliances, to ensure that Australia earns its place in the world.

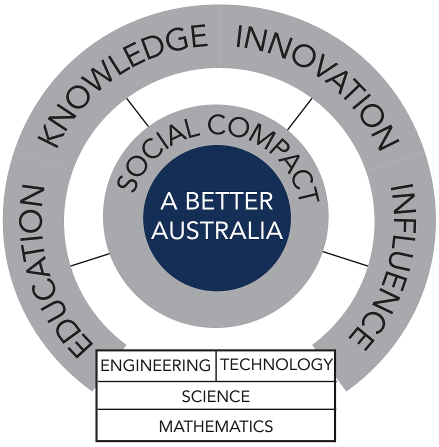
All the elements are underpinned by the enabling sciences and mathematics; and by engineering and the technological sciences – these are at least in part based on the creative application of scientific principles leading to outcomes and inventions that do not exist in nature.

The strands running through the strategy are:

- **Alignment** to clearly articulated goals;
- **Focus** on priority areas where we have competitive advantage or critical needs;
- Building **scale** so that we have the capacity to make real and enduring differences.

Once the Prime Minister's Science, Engineering and Innovation Council (PMSEIC) has reviewed the Strategy, relevant Departments and agencies will develop programs and implementation plans to put the agreed strategic actions into practice – consulting with States and Territories as appropriate. Such plans must accommodate action on multiple fronts and with multiple timeframes – and be aimed at the short, medium and long-term.

1. A BETTER AUSTRALIA



By many measures, the Australian community is one of the most successful in the world. With extensive natural resources, served by fair, stable and respected institutions, and characterised by ingenuity and hard work, many Australians are adequately prosperous and inclined to support those who are less well-off or disadvantaged.

There are, however, gathering threats and challenges to us maintaining this way of life. The five most significant societal challenges[2] that we presently face are:

- Living in a changing environment;
- Promoting population health and wellbeing;
- Managing our food and water assets;
- Securing Australia's place in a changing world;
- Lifting productivity and economic growth.

STEM is everywhere. Our nourishment, our safety, our homes and neighbourhoods, our relationships with family and friends, our health, our jobs, our leisure are all profoundly shaped by technological innovation and the discoveries of science.

Addressing these challenges requires the development of a high-quality STEM enterprise and its strategic deployment. STEM has and will continue to provide for everyone – to make available the new knowledge and technologies that are needed to address challenges, and to underpin new goods and services. Without this wellspring of new knowledge, there are hard limits to the potential for further improvement of peoples' lives.

Sustainable economic growth is a vital strategy for the future of humanity. Historically, long-term growth has invariably rested on abundant technological change, but sustainable growth will require an even higher level of ingenuity and innovation.

Societies are becoming more dependent on increasingly complex technologies, and have greater requirements for improved goods and services. Business and government must recognise both opportunities and obligations in this context.

Economies built on deep technical knowledge are more agile and better-placed for the structural change necessitated by geopolitical realignment and the move to sustainable development. New sources of technology must be prospected and tapped, placing great expectations on the whole STEM enterprise.

To recognise and take full advantage of the opportunities which STEM provides, Australia will benefit most if there is widespread and general STEM literacy throughout the community, complementing the deep expertise of STEM practitioners.

Many countries are relying on their STEM enterprise and its quality to build knowledge-based communities and economies. Australia must do the same.

There is an urgent need to act if we are not to be left behind.

We require **alignment**, **focus** and **scale** to address the societal challenges and to guide Australia's STEM enterprise now and into the future:

ALIGN

- government programs with the challenges we face at national and regional levels;
- formal and some aspects of informal education with the needs of the community, the workforce and business;
- public support for research and development (R&D) activity.

FOCUS ON

- meeting societal challenges by giving priority to related research and innovation;
- building the quality of the disciplines that are the foundation of the STEM enterprise: mathematics, the enabling sciences, engineering and technology; [3]
- building community awareness and engagement with STEM;
- Australia's research strengths and comparative advantages.

SCALE TO

- make a difference to society;
- ensure a place for Australia at the global tables of importance;
- build, attract and retain business that can prosper in the global economy.

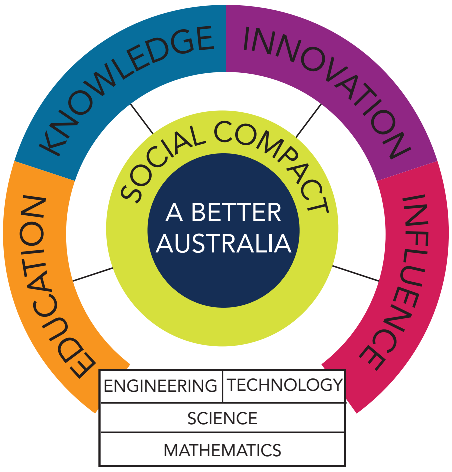
2. AUSTRALIA: 2025

A vibrant and high quality STEM enterprise will contribute expertise that will make Australia different by 2025. There will be a clear distinction between the 'ends' we seek and the 'means' to get there. The consequence will be a coordinated array of activities and programs. Australia will be able to provide a better and prosperous future for all, while securing our place in a changing world.

By 2025 we should have reached a point where Australians will understand and value the science they use in everyday life, and where the STEM enterprise will be widely accepted as a central and visible source of solutions to societal challenges. The education system will provide all Australians with the capacity and confidence to make informed choices on complex matters where STEM offers options that have ethical, economic or environmental dimensions.

- The performance of our students in STEM disciplines will rank among the best of their international peers.
- STEM will sit equally alongside citizenship and literacy in the culture and curricula of Australian schools.
- Australians will have an excellent understanding of STEM, its methods and processes, and many will be eager for advanced study in STEM.
- Australia's best will be the equal of the best in the world – and supported to sustain their place.
- Australia will have a well-qualified and increasingly diverse STEM workforce.
- Australia's STEM practitioners will maintain high ethical standards – within a vibrant social compact – and receive community support for their work.
- Australia will be well-served by effective STEM linkages between the research and innovation sectors.
- Australian STEM research will be numbered among that of high-performing nations in terms of excellence and innovation measures.
- Australia will have relied on deep technical insights to build knowledge industries and an adaptable economy.
- Australia's STEM enterprise will be globally connected and STEM will be a core feature of our diplomacy.
- Australia will be contributing at least its fair share to the stock of global knowledge.

3. THE STRATEGY



3.1 KEY OBJECTIVE

- To utilise fully Australia's capacity in STEM to secure social, cultural and economic prosperity for all Australians while positioning Australia to advantage in a changing world.

3.2 KEY ACTIONS

- Develop programs and policies to implement the Strategy.
- Build purpose and direction across the breadth of government programs.
- Expand the remit of PMSEIC to include whole-of-government policy coordination for STEM – or establish a new high-level committee to focus on this task.

3.3 RATIONALE

Australia is a country with a deeply embedded scientific culture. The culture has been supported by an array of programs delivered through multiple agencies and different levels of government.

It has grown from the very small beginnings of our first inventors, who essentially invented out of necessity, and our first universities. It has seen the founding of the Commonwealth Scientific and Industrial Research Organisation in 1926 (as the Council for Scientific and Industrial Research) and the establishment of the National Health and Medical Research Council in 1937.

Australia had learnt a lesson by 1946: we had seen that we could not simply be supplicants and expect to prosper. We had to be contributors to the world's stock of knowledge if we were to get access to what we really needed – we discovered that we had to earn a position that helped us to look after ourselves.

After 1946, Australian universities were expected to conduct original investigations.

Research became a characteristic of the Australian university sector. Today, some 60 per cent of all researchers in Australia are employed in higher education, with another 10 per cent employed in research agencies.[4] The sector dominates: only 30 per cent of Australian researchers are in the business sector by contrast with 80 per cent in the US, 64 per cent in Switzerland and 70 per cent in Japan.[5]

Australia contributes an important three per cent of the world's new knowledge, with 0.3 per cent of the world's population,[6] a solid but not outstanding performance. It illustrates, however, that Australia's STEM enterprise must be globally connected to maximise advantage – to be a contributor to, and a beneficiary of, the global search for solutions to problems that confront the planet.

It is arguably even more important now. A complex world riddled with problems that are not limited by national boundaries, provides Australia with opportunities on a scale it never had before.

For decades, support for research has been rationed; and interest in science and mathematics in schools and universities has declined. Our scientific enterprise operates at a reasonable level and has done much to support the development of Australia to this point. But the corrosive effect of rationing, ranking, short-term support especially through terminating programs, erosion of our infrastructure and the unpredictability of the critical medium to long-term investment pipeline all combine to make Australia's scientific enterprise vulnerable.

Reducing that vulnerability is a key to our future. It will take a commitment to develop and sustain our STEM enterprise. A commitment is not only about the level of resources required. It is also about how resources are deployed and sustained. It is about choices. But choices need to be based on a strategy. Careful, predictable decisions that endure are critical, particularly for foundations with long timelines – education, research and innovation.

> *This enterprise is much like any other massive, complex system. It has tremendous inertia and can keep functioning in the absence of any apparent direction… To do so, however, would be a mistake. No entity as vast, interconnected, and diverse as the science and engineering enterprise can successfully operate on auto-pilot perpetually.* [7]

Not being left behind as a nation and designing our future with STEM as a critical element ought to be the goals of governments as they make their choices.

Preparing to face national challenges requires a strategic approach to building a capacity to respond effectively and to sustaining that capacity.

We are not alone. Throughout much of the Western world, similar observations have been made.

3.4 A SENSE OF URGENCY

Around the world there is a sense of urgency – a need to improve a nation's capacity and a commitment not to take the future for granted or to presume that past practice will be good enough: *because Europe's future is at stake decision-makers must demand action on improving science education from the bodies responsible for implementing change.* [8]

Similar sentiments are expressed in developed and developing economies. And governments act. International comparisons show how Australia fares, so they are important. But cultures and economies are different. There are few international actions that could simply be translated into Australia without modification. But some common matters emerge:

- highly qualified, respected and supported teachers;
- inquiry-based teaching and learning;
- alignment of science and technology with overall national development and needs;
- long-term planning;
- international collaboration and alliances;
- increase in the share of human resources in science and technology;
- revision of graduate training to suit tomorrow's workforce;
- support for the enduring flow of new ideas;
- incentives for innovation.

Anxiety about being left behind creates a sense of urgency to address these matters promptly.

Comprehensive work on STEM education in several countries was recently completed by the Australian Council of Learned Academies. The Report for the PMSEIC provides valuable insights into what is happening.[9] A summary of some of this work is in Appendix 2.

3.5 STEM IN AUSTRALIA

Most nations are closely focused on advancing STEM, and some have evolved dynamic, potent and productive strategies. In world terms Australia is positioned not far below the top group, but lacks the national urgency found in the United States, East Asia and much of Western Europe, and runs the risk of being left behind.[9]

Australian observers draw similar conclusions to those made elsewhere: too little time on average spent teaching science in primary school; declining interest in the study of STEM disciplines in senior secondary school; limited growth, even decline in particular areas of the natural and physical sciences, in branches of engineering and information technology at tertiary level; STEM skill shortages in the workforce.

Australia's productivity and competitiveness is under immense pressure. A key way to meet the emerging challenge of developing an economy for the 21st century is to grow our national skills base – particularly the Science, Technology, Engineering and Mathematics (STEM) skills of our school leavers. Our relative decline of STEM skills is holding back our national economy and causing real frustration for employers.[10]

It has been estimated that 75% of the fastest growing occupations require STEM skills and knowledge. Yet this Australian Industry Group research report reveals a disturbing picture in this area. Young people in schools and universities are not acquiring the STEM skills we need for our future prosperity. [11]

It is not that we lack programs in Australia. There have been many programs, large and small, built over decades. What we do lack is a national approach to STEM.

In research and innovation for example, the Australian Government invested close to $9 billion in 2012-13 through a suite of 79 programs across 14 portfolios.[12] Each program serves a defined purpose related to the priorities of the department or agency that administers it.

It is important to understand how each program will contribute to the wants, needs and aspirations of Australians, and to ensure their cumulative effect will build long-term prosperity, capacity to take advantage of unforeseen discoveries and applications, and resilience to cope with unexpected adversity.

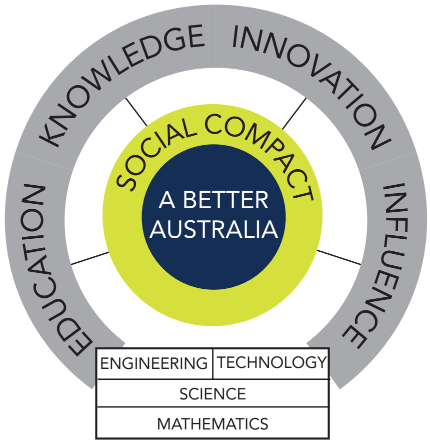
Investment of public funding for STEM requires a systematic approach to ensure maximum return.

We require a whole-of-government approach to STEM.

In the US, for example, this is accomplished by the National Science and Technology Council (chaired by the President of the United States) which *prepares coordinated interagency research and development strategies that are coordinated across Federal agencies to form investment packages that are aimed at achieving multiple national goals.* [13]

The Australian federation could benefit from such an agency; the Prime Minister's Science, Engineering and Innovation Council (chaired by the Prime Minister) could add this coordinating function to its existing strategic advisory role. Or a new body with specific coordinating functions could be established.

4. A SOCIAL COMPACT FOR STEM



The value of any investment in STEM will be enhanced if there is clear understanding that practitioners work with and for the community.[14,15]

STEM will work best when it is accorded a 'Social Compact' from the community. In return the community must have confidence that the approaches taken by STEM practitioners and the quality of their work meet the needs, aspirations and ethical expectations of the community.

> Since STEM is not the only source of insight and illumination in human affairs, STEM practitioners have no special status in respect of the moral dimensions of the utilisation of STEM; this is the province of society as a whole.

4.1 KEY OBJECTIVE

- A refreshed Social Compact that articulates the responsibilities and obligations of the three key parties (governments, community and STEM practitioners).

4.2 KEY ACTIONS

- The Australian Government will act to facilitate the development of the Compact – drawing on needs and aspirations of the three parties to the Compact.
- The Australian Government will promulgate the Compact when it is agreed.
- Research institutions will update and maintain effective internal processes to monitor and regulate standards.
- The substance of the Compact will commit STEM practitioners to:
    - continued high ethical standards;
    - clearly articulated mechanisms by which standards are maintained;
    - provision of a bountiful stream of new knowledge and practical solutions to short and long-term problems of benefit to the community;
    - following a best practice, regulatory framework for STEM;
    - describing benefits and risks, and the limits of knowledge, when contributing to policy development;
    - open access to research outcomes of publicly funded Australian STEM research.
- The community in return will commit to:
    - supporting STEM through sustained public and private investment at an appropriate level to keep it comparable with the best performing nations;
    - allowing and respecting that the methods and processes of STEM can be left to the practitioner peer community to design and monitor;
    - supporting a stable policy environment;
    - ensuring regulatory frameworks adhere to best practices.

4.3 RATIONALE

To address effectively challenges and provide benefit to Australia, STEM has to work for and with society. Acceptance by the community of the outcomes from STEM will only arise when the community has confidence in Australia's STEM enterprise. This will be advanced through commitment to a Social Compact within which all the key parties understand their obligations to each other.

STEM is critical to our future, but it does not operate in isolation.

The values, modes of practice, and means of discovery in law, humanities, visual and performing arts, philosophy, ethics, politics and religion offer alternative ways of illuminating issues and revealing options for action.

> *Scientific integrity is at the core of producing and using good science. By being open and honest about our science, we build understanding and trust.* [16]

Given the importance and ubiquity of science and technology, however, there has been a tacit but long-standing compact between the beneficiaries of STEM – the community at large, and the practitioners of STEM – scientists, technologists, engineers and mathematicians.

As we refresh the Compact it is important to recognise:

- the effort, foresight and investment required to discover and apply new knowledge;
- the folly of drawing on previous efforts of STEM practitioners without renewal;
- the vulnerabilities that follow from reliance on the knowledge and skills of others;
- the need to build community confidence in its STEM enterprise;
- the importance of keeping the community informed: what is being done, why, how and with what potential benefit and any risk.

This is an issue we share with others. A League of European Research Universities (LERU) report emphasises both the importance and the need for care in using research.[17]

> *Science doesn't replace moral judgement. It just extends the context of knowledge within which moral judgements are made. It allows us to do more, but it doesn't tell us whether doing more is right or wrong.* [18]

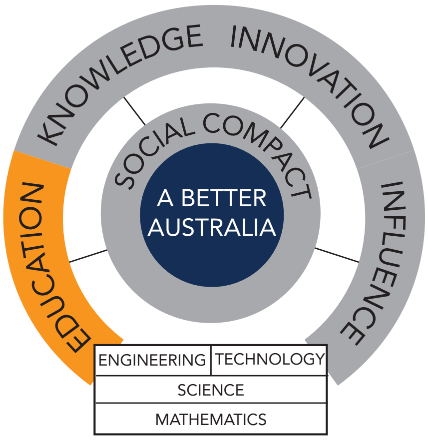
The report highlighted **four basic principles**.

- *Quality matters.* For research to be effective, it has to be good and recognised as such.
- *Foresight matters.* Politicians and researchers must look ahead to the *grand challenges of society and identify key, long-term research problems*.
- *Timing matters.* Opportunities for action must be seized at the right time.
- *Communication matters.* Too much research is presented for the peer audience when, in fact, the audience is politicians and decision makers. Research and policies need to include the community, and need to ensure that the benefits and any risks are clearly articulated.

The Australian Compact requires STEM practitioners to be open in communicating their work and its significance to society. Practitioners will make clear the professional integrity of STEM practices, and the commitment of STEM practitioners to contributing to societal benefit.

In return, a receptive society with confidence in STEM will ensure that the resources provided to STEM are adequate to achieve the aim of making 'A Better Australia' in an acceptable timeframe.

5. PATHWAYS TO A BETTER AUSTRALIA: EDUCATION



Becoming 'A Better Australia' starts with education.

5.1 KEY OBJECTIVES

- The Australian education system, formal and informal, must be organised:
  - first to lay the foundation for all Australians;
  - then, to refresh constantly a STEM literate community;
  - to produce and regularly refresh a STEM skilled workforce – including the research workforce;
  - to develop proficient STEM practitioners in suitable numbers.
- Promote 'citizen science'[19] to engage more of the community with STEM on an avocational basis.

5.2 KEY ACTIONS

Contemporary content is important – but so too is an understanding of the scientific method, and the philosophy and history of science.

> A responsibility of all levels of governments is to prepare and equip society to adapt to changing circumstances and to make sound choices. Manageable threats can become serious crises if a community is made nervous by how evidence is used or misused.

5.2.1 AT ALL LEVELS OF EDUCATION

In order to reverse the declining trends in STEM participation:

- Curricula and the corresponding syllabi should reflect the transient and evolving character of the factual knowledge of STEM and provide a strong focus on the practice of STEM.
- Curricula should be delivered to students in ways that encourage curiosity and reflection.
- Inquiry-based learning should be emphasised, along with the teaching of critical thinking and the scientific method.
- Future needs for a well-qualified and increasingly diverse STEM workforce should be highlighted to guide study decisions of students at all levels of education.
- A sufficiently large pool of high quality STEM graduates ready for employment in any sector of the Australian economy should be produced.
- Enduring and real partnerships between employers and education and training providers should be forged in ways that are more substantial and sustained than anything done before.
- Approaches should be developed and implemented to raise the STEM participation of females, and disadvantaged and marginalised students.

5.2.2 SCHOOLS

Schools combine the challenging roles of providing the foundation for STEM practitioners of the future on the one hand, with developing a scientifically literate and numerate society on the other. Inspirational teaching at school is crucial for nurturing student interest in science and influencing their study and career choices.

- Incentives to encourage high-achieving students to enrol in pre-service education programs for potential STEM teachers should be introduced.
- The recruitment, pre-service preparation and in-service support for all teachers should be improved to ensure well-versed teachers in STEM disciplines.
- The Australian Institute of Teaching and School Leadership accreditation criteria should be implemented as soon as practicable. These require *students to have achieved a discipline-specific qualification, relevant to the Australian Curriculum or other recognised areas of schooling provision. For secondary teaching this is at least a major study in one teaching area and preferably a second teaching area comprising at least a minor study.* [20]
- Teaching time devoted to science (as 'science') should be increased in primary schools from an average of less than five per cent to closer to the Western European average of nine per cent. [21]

5.2.3 POST-COMPULSORY EDUCATION

Post-compulsory STEM education must prepare the next generation of STEM practitioners, including STEM teachers, while offering flexibility for graduates who intend to take their STEM skills into other areas of endeavour.

- The widespread use of flexible sequences of study that make it possible to master STEM and non-STEM disciplines together should be encouraged.
- Student study trends in universities and in VET should be closely monitored so that incentives can be introduced to ensure that important disciplines do not wither because of a present lack of student interest.
- Transfer with appropriate credit between various parts of the education sector (and even within) should be seamless to the student.
- The value of discipline-based content and the underlying process of STEM methods should both be highlighted.

> To reverse the trend for decreasing STEM participation in schools, federal and state governments will need to cooperate to drive the school education system away from educating students as we used to, and towards preparing students for a future increasingly bound to STEM. These changes encompass educational values, curriculum, and accreditation procedures so that school leavers will be well-equipped to participate in the then contemporary workforce.

5.2.4 EDUCATION AND THE WORKFORCE

Existing linkages between the supply and demand sides of the Australian STEM workforce must properly address workforce needs into the future – including those of the research workforce.

- Commit to funding for skilling and reskilling the workforce.
- Enduring partnerships between employers and education providers should be built to ensure that graduates are 'work-ready' for the current workforce, while broadly educated in both discipline content and the scientific method to be able to adapt to future workforce needs.
- Continuing development opportunities for the workforce should be ensured through formal and informal training.

5.2.5 COMMUNITY EDUCATION

The levels of STEM literacy in the community will only be improved through better engagement with science and mathematics in schools and an increased engagement of the community with the STEM enterprise. In the US, the White House recently celebrated "champions of change": individuals and organisations that have engaged citizen scientists and non-experts in scientific research.

- Adequate support and coordination frameworks should be introduced, to encourage and promote such citizen science as a means to engage more of the community (and teachers) with STEM on an avocational basis.
- Museums, libraries, the learned academies and others should be supported to offer systematic outreach activities.

5.3 RATIONALE

Science plays an ever increasing part in our lives. We make important decisions about our health and that of our family, for example, in choosing to vaccinate our children. We use smart phones to communicate and GPS in our cars to get from place to place. We regularly hear or read about climate, genetically-modified food, space exploration, the use of DNA in forensic science, and new drugs to treat disease.

> *We live in a society exquisitely dependent on science and technology, in which hardly anyone knows anything about science.* [22]

There is currently a general view that the level of scientific literacy and numeracy in the community is low. [23] An understanding of science and how it works is essential for the community to make informed choices on issues that have a scientific basis.

Education in STEM is the key to broadening and deepening the community's grasp of what STEM is saying and doing about the complex challenges facing society.

As the world changes, the demands on STEM educators are becoming more urgent – and the reasons are common: more and better STEM literacy, more and better STEM practitioners and more and better skilled employees for the economy-at-large.

> *Appreciating the scientific process can be even more important than knowing scientific facts. People often encounter claims that something is scientifically known. If they understand how science generates and assesses evidence bearing on these claims, they possess analytical methods and critical thinking skills that are relevant to a wide variety of facts and concepts and can be used in a wide variety of contexts.* [24]

If we are to keep pace – or even lead – we too need to do things differently. Not just continue the old ways even with relatively minor, if frequent, adjustments.

> We in Australia have a choice. We can act strategically to prepare for a future we want, or we can settle back and persuade ourselves that what we do now will be good enough – just because we do it now.

The magnitude of the challenge we face is substantial.

And it will be met only if all parts of the Australian education systems, formal and informal, play their part. But, like in the US, it will not be easy to go beyond rhetoric to action, to outcome.

The US has called for a 30 per cent increase in STEM graduates in one decade.

Hunter Rawlings, now head of the Association of American Universities stated: …*Those recommendations are deceptively challenging and will require overcoming steep obstacles at the thousands of US colleges and universities that educate the next generation of workers. Changing the academic culture is hard, and I am not going to pretend that we are assured of success. We're not…* [25]

The Australian system is different. The Australian Government has valuable negotiations with each university, and they provide the opportunity to develop suitable arrangements to meet national goals.

The pressure of changes in the global socio-economic environment in which Australian businesses operate will lead to the continuing evolution of Australia's needs from its education system.

As Australia builds on its comparative advantage in exported services and extractive and agricultural industries, a growing proportion of the workforce will require ever greater STEM competencies and skill sets. This runs alongside a move towards a high-value, export-oriented manufacturing sector which offers greater prospects for future employment.

Australia's adaptation to this evolutionary pressure will depend on the capacity of employers and employees to increase their STEM skill levels so that businesses have the flexibility and agility to respond to change.

A world-class STEM workforce is essential to virtually every goal we have as a nation. [26]

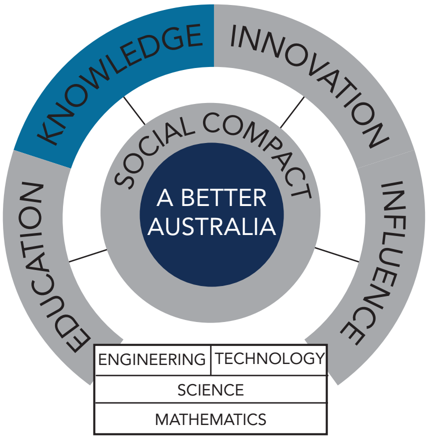
These global developments highlight the need to start now. In the US, it is suggested that 60 per cent of the workforce of 2020 will require skills held by only 20 per cent of the current workforce.[27] Australia may be different, we don't know.

Studies from the US and Australia show that STEM practitioners have very high rates of post-secondary and post-graduate qualifications.[28] STEM employment opportunities are buoyant. In the US, many STEM employment opportunities arise in professional, business and information services.[29] It is not seen there as a failure if STEM qualified individuals take their talents and skills into sectors of the workforce that do not explicitly require STEM content.

Australia, like many other countries, has limited statistics and information regarding the development and placement of entrants into the STEM workforce, their integration into the Australian economy, and the projected demand for employees with STEM skill sets across the range of Australian qualifications. Without this knowledge, Australia lacks a sufficiently clear picture of what business requires from a STEM education.

There is a low rate of entry of STEM researchers in the business sector.[30] Some of Australia's brightest and most creative people are not being integrated into the broader economy. Universities and business share an interest in addressing this lost opportunity – through genuine partnership.

6. PATHWAYS TO A BETTER AUSTRALIA: NEW KNOWLEDGE



Australia must be a contributor to a world that relies on a steady flow of new ideas.

6.1 KEY OBJECTIVES

- Support our need to understand both the natural world and the constructed world.
- Sustain a diverse portfolio of research that is high calibre, creative and groundbreaking.
- Encourage multidisciplinary approaches to research.
- Ensure that Australian STEM is global in reach with a particular focus on the region.

6.2 KEY ACTIONS

- The discovery and dissemination of new knowledge for common use must be supported.
- The best of Australia's researchers should be supported at a level that will enable their output and hence their contribution to global understanding to sit comfortably alongside the output of the best of their peers overseas.
- Short-term or terminating funding should only be used sparingly, and then only with a strategic purpose.
- Research infrastructure that is strategic, collaborative and well planned should be built with funding arrangements that are predictable and holistic.
- Publicly funded research agencies should be sustained to undertake mission-directed STEM R&D.
- A proportion of federal government expenditure should be aligned with the broader societal challenges and Strategic Research Priorities.[32]
- An Asian-Area Research Zone should be established so that strategies, infrastructure, researcher exchanges and research programs can be developed to focus on shared priorities within the region.

Funding for research is an investment in national productivity and wellbeing.[31]

6.3 RATIONALE

The Australian STEM enterprise requires ambitious and long-term aspirations that provide stability and confidence for both public and private STEM practitioners.

History has shown that it is federally- sponsored research that provides the truly 'patient' capital needed to carry out basic research and create an environment for the inspired risk-taking that is essential to technological discovery. [33]

The tradition of sharply delineating 'pure' and 'applied' dimensions of science has been a characteristic of Australian discourse for some time, and is an unhelpful dichotomy.

The community receives optimal returns from STEM (and other) investments when the whole spectrum of research is fully supported.

As in other creative human activities, the STEM enterprise thrives on curiosity. Curiosity-based work, or the urge for understanding, must be supported alongside work that is directed towards obtaining specific identified outcomes.

High upfront costs, uncertainty of outcome, openness of knowledge and the potential re-use by others all reduce the likelihood of substantial business support for research aimed fundamentally at understanding the world as it is.

Governments have the critical responsibility to inject the 'patient' capital to finance this curiosity-led research. Government investment in research thus supports the national interest, including:

- the social return on investment from trained STEM graduates at the doctoral level where the potential private cost is high;
- the value of multiple use and re-use of pre-commercial STEM knowledge where uncertainties about when and how the discoveries will be used may limit business interest;
- providing access to data from publicly funded research;
- the tradition of academic freedom in research and teaching;
- the freedom of STEM practitioners to monitor, advise about and respond to STEM developments abroad and across Australia.

We cannot risk our future growth and competitiveness by cutting back now on investment in education, research and innovation that is necessary for long-term and sustained recovery.[34]

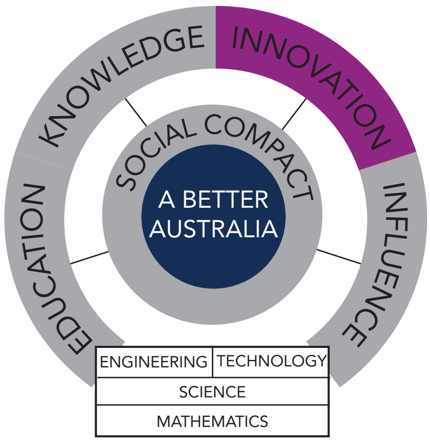
Through the development and promulgation of Societal Challenges and Strategic Research Priorities, the Australian Government now has the means to invest a proportion of its research support selectively.

To gain maximum benefit from our STEM investments in knowledge generation, we must link to the work of the international community. Ideally, a proportion of our effort will be directed to strategic work that relates to shared priorities.

Transformational change is driven by turning curiosity into knowledge, forming a reservoir from which we draw for application and innovation.

Many of the challenges that confront Australia are similar to those of our regional neighbours. There is now an opportunity to share talents, skills, expertise and infrastructure that arises rarely. Accordingly, it is proposed that Australia seek to enter into a partnership with neighbours to establish an Asian-Area Research Zone.

7. PATHWAYS TO A BETTER AUSTRALIA: INNOVATION



Australia must integrate its innovation system with the STEM enterprise to ensure that we can rapidly turn knowledge into new and improved goods and services.

7.1 KEY OBJECTIVES

- Increase the translation of ideas to new and improved goods and services.
- Establish a National Innovation Council.
- A culture change – to minimise risk aversion and maximise risk management.
- A culture change – to enhance links between business and publicly funded research agencies and universities.
- A culture change between education providers and business to meet the need for a well-prepared and STEM skilled workforce.

7.2 KEY ACTIONS

Australian Government innovation incentives should focus on, and support, actions that are likely to change the culture.

- The flow of STEM qualified workers between all sectors of the economy should be encouraged.
- Potential employers of STEM graduates at all levels of qualification should be actively engaged with all of the institutions in which STEM education is provided.
- Opportunities for education providers to integrate study and experience in the workplace for credit should be widespread.
- A proportion of public subsidies should be focused on supporting research translation to meet societal challenges.
- A proportion of public investment should be focused on the translation of STEM discoveries into products and services to take to market, nationally and internationally.
- A National Innovation Council should be established to develop strategies that accelerate the translation of ideas into products to market.
- Intellectual property barriers that slow knowledge diffusion, collaboration or commercialisation should be removed.

[Innovation]…involves decisions made in both private sector and government sectors to invest time, effort and money in exploring new ideas. From a business perspective, the profit motive and competition will be important drivers of innovation.[35]

7.3 RATIONALE

Success in the 21st century is driven by excellence in science, technology and innovation – by pushing the boundaries of knowledge and by applying discoveries to produce new or improved products and processes…the most competitive economies are built on the recognition that science, technology and innovation drives growth, prosperity and high quality of life.[37]

Innovation provides a number of tangible and intangible benefits, including greater market diversity, increased collaboration and connections, higher levels of employment and increased skill levels.[36]

Australia's future economy will increasingly rely on innovations to improve productivity. Productivity is a measure of how efficiently a society employs finite resources such as land, labour and equipment to produce or develop goods and services.[38] Productivity can be lifted by increasing the quantity, and also the value of outputs.

Productivity growth driven by innovation, including innovation based on STEM, offers significant benefits for the community. The Australian innovation system has not adequately integrated with the STEM enterprise, however. We need to address the structural barriers that inhibit the flow of people and ideas between the private and public sectors.

Innovation does not just happen. A strong, dynamic and sustainable Australian STEM research enterprise can provide a foundation for innovation and strong business performance, stimulate the development of new products, processes and businesses, and provide the deep technical knowledge that underpins a resilient economy.

Better integration of the public and private STEM sectors will strengthen the innovation system.

Linkages should be developed early during school education and amplified in later years. Increased mobility and shared training events including business as well as students and staff from the education sector will foster higher levels of STEM performance. Stronger collaboration between business and the public STEM sector would arise if Australia achieved higher levels of researcher employment in the private sector.

The incentive and reward systems for teachers and public sector researchers should be adjusted to encourage and properly recognise their contributions to the Australian STEM enterprise and innovation system. A self-reinforcing reward system encouraging connections and mobility between business and the public sector would drive the long-term culture change that is required.

Culture change is critical. Australia, for example, currently has many business investment and incentive programs to support an array of R&D activities at national and regional levels.[39]

Business is both a producer of STEM research and a client of public sector STEM research. For every $1 invested by government in Australian public R&D, business invests $2 in business R&D.[40]

However, after decades of inducement, business innovation in Australia most often takes place within firms, or between firms and their domestic customers.[41] It was reported in 2011 that just four per cent of companies developed innovations new to the world while more than 60 per cent kept innovations within the company.[42]

There is no argument that innovation within businesses is important – but the **proportions** are surely inappropriate.

Engagement between STEM researchers in business and public spheres in Australia should be the norm, not the exception. This engagement should occur at the level of knowledge and practice, and also at the level of values, strategy and policy.

Australia's comparative advantages and needs, should inform the focus of a substantial proportion of public support for both research and innovation.

Factors which make us different include natural endowments that support prosperous business and export trade in minerals and agriculture, remoteness, a relatively small market leading to low levels of participation in global high-technology manufacturing and services, and an unusually high proportion of multinational businesses headquartered elsewhere, with mainly sales and marketing operations in Australia.

Geographical factors confer some comparative advantages exploited by Australian business; however, they entail vulnerabilities that are widely understood. A focus on STEM-based innovation and its global reach will help build resilience into Australian business and the economy.

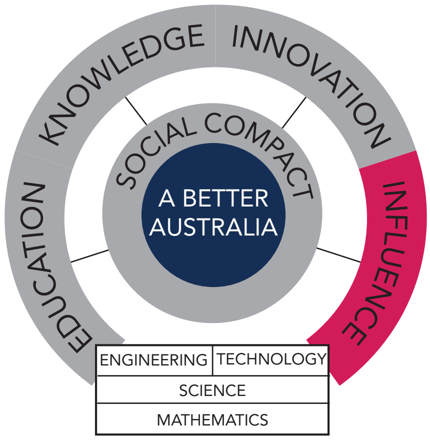
Australia has much to learn about the business and economic benefits that can be found in the interplay between STEM and innovation that exists in places like the US and Europe. While the Australian economy is different, it is unarguable that advances in STEM drive substantial innovation, and that Australian businesses must be well-positioned to translate these advances into new and improved products and services.

Geographical factors shape many of Australia's comparative economic advantages and disadvantages, and explain why our business profile is different from most countries with which we are compared.

The success of Commercialisation Australia shows what can be achieved.[43] Now it is about scale.

To capture the full suite of opportunities, a National Innovation Council working alongside research funding agencies should be established.[44] The National Innovation Council would be industry-led and work cooperatively with the research funding agencies to share responsibility for the integration of the business sector's needs for research to support innovation that leads to productivity growth.

8. PATHWAYS TO A BETTER AUSTRALIA: INFLUENCE



Australia's STEM enterprise must be strategic and collaborative at an international level to draw maximum benefits while positioning Australia to advantage in a changing world.

8.1 KEY OBJECTIVES

- Strategic and funded government-to-government alliances.
- Leverage STEM and its global reach to strengthen Australia's position and contribute to a better world.

8.2 KEY ACTIONS

- Bilateral and multilateral strategic relationships with governments of countries that have complementary research priorities and shared challenges should be developed in order to:
    - enable timely and cooperative access to major infrastructure and resources;
    - increase awareness of international STEM developments;
    - encourage collaborative international technology start-up ventures;
    - promote international industry-public sector research collaborations.
- Individual researchers and teams should be supported to develop international networks and establish collaborative activities.
- STEM should be leveraged to support Australia's international relations.
- An Asian-Area Research Zone should be established (see section 6).

8.3 RATIONALE

The STEM enterprise is truly global. Practitioners and scholars in these fields share their knowledge and skills with limited regard to national boundaries.

> *Knowledge belongs to humanity, and thus science knows no country and is the torch that illuminates the world.*[45]

Today, many profound discoveries in STEM knowledge and practice are spread across the world in a matter of days, if not hours.

STEM bridges cultural divides through its absence of ideology and use of rational dialogue. It also addresses problems of common interest to many nations supporting a second level of diplomacy through non-traditional alliances.

Australia must be a contributor to the world stock of knowledge through education, R&D, innovation and business. In this way, the Australian Government, business and public STEM practitioners gain a seat at the international table. Engagement through STEM provides the opportunity to tie together other areas of international presence, such as development assistance and global security. STEM must therefore be a key consideration in foreign policy formulation.

International collaboration benefits all parties, regardless of their comparable positions and level of expertise.

Australia's STEM enterprise must be internationalised at its core: global presence is essential, not an optional add-on.

Strategically important research collaborations require the sustained commitment and support of the Australian Government.

Given constraints on funding, Australia's international STEM profile needs to be guided by a strategy that goes beyond support for individual cases. It should be driven by creating opportunities for collaboration where there is a convergence of strategic interests. Investment in international STEM activities should ensure an alignment between Australia's capacity and national interest, with the research questions relevant to international partners.

Australia's STEM is respected for its contribution to international solutions to global challenges, especially in systems science where, for example, oceans, atmosphere, space and epidemiology are global responsibilities. International scientific cooperation is necessary to address shared global challenges, bringing to bear infrastructure and capabilities that no one nation can easily provide on its own. Marshalling resources generally sees better results more quickly.

Australia's strategy for international engagement in STEM will require consideration of both better performing countries and emerging countries in our region. This requires two elements: one that addresses shared strategic research priorities alongside researchers in STEM-rich nations; the other nurtures relationships with rapidly growing or developing nations in our region to build genuine and enduring partnerships for mutual benefit.

The G8 science ministers recently stated that *coordination of global scientific research is needed to address global challenges and maximise the social and economic benefits of research.*[46]

If Australia is to be successful in transforming to a new economy that can meet the challenges of the 21st century, then research and innovation needs to be at the very heart of Australia's economic, industry, social, national security and foreign policy. [47]

Australia will come late to, and perhaps miss, key international collaboration opportunities, especially in emerging countries, unless there is an active identification of opportunities. All such coordination and interaction must consider political, diplomatic and strategic terms to gain the most benefit for all parties.

The benefits of international engagement through STEM are wide-reaching. Shared priorities provide the platform for collaboration. Researchers who work overseas are immersed in different cultures and environments. International collaboration provides the means by which these new ideas and different practices can be brought back to Australia to contribute to the STEM enterprise at home.

Australia is an open society and our borders are porous to the flow of human and physical capital and knowledge. The ongoing ebb and flow of people and ideas is important for the vibrancy of Australia's STEM enterprise. To secure long-term benefits for STEM in Australia we must ensure that there is stable, enduring capacity to extract a net national benefit from this flow.

APPENDIX 1: SCOPE OF STEM

Science, technology, engineering and mathematics are distinct and complementary approaches to knowledge and practice that have been proven to produce benefit to society.

Mathematics and the disciplines within the natural and physical sciences contribute broadly to all disciplines and practices used for the betterment of society.

Mathematics aims to understand the world by performing symbolic reasoning and computation on abstract structures. It unearths relationships among these structures, and captures certain features of the world through the processes of modelling, formal reasoning and computation.

Mathematics contributes to biology, medicine, social sciences, business, advanced design, climate, finance, advanced materials, and many more. This involves integration of mathematics, statistics, and computation in the broadest sense and the interplay of these areas with areas of potential application.

There are three broad categories of science: natural and physical sciences, human sciences, and the design sciences. Common to these are the importance of classification, empirical studies, understandings of the provisional nature of knowledge, the use and limits of causality, replication and predictability in different settings, and subjective and objective elements of the work of scientists.

For the purposes of this strategy the scope of science in STEM is limited to the enabling disciplines within the natural and physical sciences. The natural and physical sciences encompass: astronomy and the earth sciences, physics, chemistry, the materials sciences, biology and biomedical science. These sciences rely on causal relationships, characterised by systematic observation, critical experimentation, hypothesis-formation and falsification.

Notwithstanding this focus, addressing the societal challenges fully requires the knowledge and skills of other science disciplines.

- The human sciences encompass: psychological, social, economic and health sciences. These sciences attempt to understand human and historical life, which involves theories and methods that are more diverse and contested than in natural and physical sciences research.
- The design sciences encompass: architecture, urban planning and design studies. Research methods differ from those of research in the natural or human sciences owing to the future-focused and unpredictable nature of design science problems and puzzles.

Engineering as a profession draws on the knowledge and methods of science, but science is far from sufficient for successful practice. Real-world engineering must address and solve immediate problems, sometimes without the luxury of abundant or complete knowledge taking account of aesthetics and uncertainties.

Technology provides goods and services to satisfy real-world needs. Building on the growing importance of information and communication technologies as the Internet has developed, technology increasingly encompasses the cross-section of knowledge and skills that drive the advance of the business, government and non-government service sectors – the so-called *service sciences*.

Engineering and technology are critical factors in the long-term economic growth of modern industrial societies. They function within the larger social environment to sustain the innovation process. The output of engineering and technological activities is a product or a service that must eventually stand the test of users and the marketplace.

APPENDIX 2: INTERNATIONAL COMPARISONS - SELECTED SUMMARIES

A comprehensive report on STEM education in several countries was recently completed by the Australian Council of Learned Academies. The report for the Prime Minister's Science Engineering and Innovation Council provides valuable insights into what is happening internationally. Some of what follows is drawn from this report *STEM: Country comparisons.*[48]

IN OUR REGION

Asian economies with very high performing education systems have established national policies around science and technology more broadly, and university and industry driven research and development.[49]

SINGAPORE [50]

The policy to have a strong focus on mathematics, science and technical skills has been in place since 1968 with the formation of the Ministry of Science and Technology. This effort was further enhanced in in the 1990s with an emphasis on developing human resources in high technology and the knowledge economy through post-secondary and tertiary education.

Recognising that having sufficient human capital in science and technology is essential for the development of the country, the government made a paradigm shift in the education system by focusing on innovation, creativity and research.

Our students spend significant amount of curriculum time mastering the basics of numeracy from Primary One, before embarking on the study of Science from Primary Three.[51]

SOUTH KOREA [52]

It is hard to remember, given South Korea's present level of development, that, in 1948, (when) a modern education system began to be built there, the very vocabulary to talk about modern science and mathematics hardly existed in the Korean language and had to be invented before textbooks could even be written…Serious and sustained special attention to scientific and technical education came only in 1973 with the establishment of vocational schools associated with the movement to scientificize the whole people.[53]

From a policy perspective, the Korean case study provides a unique example of national government long term planning for science and technology and economic development, which has clearly translated to a high-performing education system, and extremely high levels of participation in STEM disciplines in higher education undergraduate and doctoral programs (principally including engineering).

CHINA [54]

In 2006, a new Science and Technology development goal to 2020 was announced covering agriculture, industry, high-tech and basic science research.

China has adjusted its Science and Technology (S&T) strategies to align them better with the overall national strategy and the goals for economic and social development. The important roles that S&T play in China are said to be threefold:

- the advancement of S&T is the radical motive of social and economic development;
- scientific innovation will accelerate the transformation of economic development, which is the first priority of the national strategy;
- S&T are not only about knowledge and skills, but are also closely related to the national culture and spirit. The scientific spirit and qualities of a nation determine the future and vitality of the nation.

INDIA [55]

India's national Science, Technology, Innovation policy was released in January 2013. It aims to:

- position India among top five scientific powers in the world by 2020;
- make careers in science, research and innovation attractive and set up world class R&D infrastructure;
- raise gross expenditure in research and development to two per cent from the present one per cent of the gross domestic product in this decade by encouraging enhanced private sector contribution;
- increase the number of full time equivalent R&D personnel in India by at least 66 per cent of the present strength in five years;
- increase accessibility, availability and affordability of innovations, especially for women, differently-abled and disadvantaged sections of society.

TAIWAN [56]

Government commitment to STEM is characterised by long-term planning (1959 Long-Term National Science and Technology Plan; National Long-Term Science Development Committee; 1969 Twelve Years National Science and Development; Industry Technology Research Institute; Professional Training Golden Regulations).

Science education is part of Taiwan's 'education for all' mission, emphasising the development of science literacy, individual creativity and innovative ability. In the first National Science Education Conference in 2002, the goals of science education in Taiwan were stated as *enabling every citizen to take delight in learning science and understand the application of science, be curious about the profoundness of science and appreciate the beauty of science.*

EUROPE

In the recent Eurydice report on science education, Androulla Vassiliou, European Commissioner for Education and Youth, noted: *many international reports identify the potential shortage of human resources in key scientific professions and call for modernising science teaching in school.*[57]

In 2011, UK employers and businesses welcomed support for STEM subjects: the Confederation of British Industry recently conducted a survey of its members and found that 43 per cent of respondents listed raising the number and quality of STEM graduates as one of the top three priorities for the Government in this area.[58]

The report states that: …*(STEM) skills underpin the UK's ability to compete and grow in a range of industries. Demand for these skills is strong across the economy and is set to grow in the next three years – meaning STEM study will continue to unlock an array of opportunities for young people at every skill level. Action must be taken by government and businesses to ensure schools, colleges and universities can provide high quality, business-relevant STEM education and training which is appealing to students from every background.*[59]

European business leaders and education policy makers have launched an €8.3m initiative to inspire students to study science at university – a much needed skill set if the region's economy is to recover and flourish by 2020. *We cannot risk our future growth and competitiveness by cutting back now on investment in education, research and innovation that is necessary for long-term and sustained recovery.*[60]

NORTH AMERICA

CANADA

Canada's Science, Technology and Innovation System: Aspiring to Global Leadership[61] celebrates the high quality of Canadian talent and their strength in generating knowledge. It also reports that… *to a significant extent, Canada's success in the 21st century will be determined by our ability to harness science, technology and innovation to drive economic prosperity and societal well-being.* The report also identifies areas where performance is lagging and where there must be improvement, two of which are an increase in the share of human resources in science and technology and the number of doctoral degrees in science and engineering per one hundred thousand of the population.

THE UNITED STATES

Our education system is not producing enough STEM-capable students to keep up with demand both in traditional STEM occupations and other sectors across the economy that demand similar competencies... Diversion, coupled with the observation that the market for STEM competencies is broader than the market for STEM workers, illuminates why we look like we're producing enough STEM workers – but we are actually not.[62]

The emphasis on STEM education and research in the US was refreshed recently with a Report from the Committee on STEM education, National Science and Technology Council.[63]

It has five priority areas and is a five year plan:

- improve STEM instruction;
- increase and sustain youth and public engagement in STEM;
- enhance STEM experience of undergraduate students;
- better serve groups historically under-represented in STEM fields;
- design graduate education for tomorrow's workforce.

The plan reflects *the needs of our nation, the alignment of priorities of both the Administration and Congress and can draw effectively on Federal STEM-related assets.*[64]

The commitment includes financial support to produce 100,000 new STEM teachers, and to add one million additional graduates in STEM over the next decade.

APPENDIX 3: CONSULTATION LIST

Australian Academy of Science

Australian Academy of Technological Sciences & Engineering

Australian Academy of the Humanities

Australian Bureau of Agricultural and Resource Economics and Sciences

Australian Council of Deans of Information and Communications Technology

Australian Council of Deans of Science

Australian Council of Engineering Deans

Australian Industry Group

Australian Mathematical Sciences Institute

Australian Nuclear Science and Technology Organisation

Australian Research Council

Academy of Social Sciences in Australia

Business Council of Australia

Commonwealth Scientific and Industrial Research Organisation

Defence Science and Technology Organisation

Department of Education, Employment and Workplace Relations

Department of Industry, Innovation, Climate Change, Science, Research and Tertiary Education

Engineers Australia

Group of Eight Engineering Deans

International Centre for Radio Astronomy Research

Melbourne Research, The University of Melbourne

National Committee for Mathematical Sciences

National Health and Medical Research Council

Prime Minister's Science, Engineering and Innovation Council

Questacon

Universities Australia

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