International Journal of Innovation in Science and Mathematics Education, *26*(8), 67–80, 2018

Transnational Examination of STEM Education

Rachel Sheffield[a], Rekha Koul[a], Susan Blackley[a], Ella Fitriani[b], Yuli Rahmawati[b] and Diane Resek[c]

Corresponding author: Rachel Sheffield (Rachel.Sheffield@curtin.edu.au)
[a] Curtin University, Perth , Western Australia
[b] Universitas Negeri Jakarta,Indonesia
[c] San Francisco State University, USA

Keywords: STEM, Makerspace, transnational, STEM trends, educators, legislation

International Journal of Innovation in Science and Mathematics Education, *26*(8), 67–80, 2018.
Special Issue: STEM Education

Abstract

STEM in its multiple forms (STEAM, STEMM) has been presented as a solution for many of the world's problems. If its hype is to be believed, it is through the power of STEM and the creation of STEM or S.T.E.M scientists, technologists, mathematicians and engineers that the world economy will be restored; and global issues can be addressed. Whilst it is easy to get caught up in the locally created hype around STEM and the creation of a STEM pipeline, it is pertinent and timely to examine the current status and trends of STEM education across the world at the school and tertiary levels. In this paper a team of STEM educators explores the context of STEM within their respective countries, and together it is hoped that a clearer, shared view of STEM education is developed, and a future for STEM education is imagined. This paper examines the state of STEM education in four countries: Australia, India, Indonesia and the United States of America (USA). Expert STEM educators from each country reflect on how STEM education is currently viewed and implemented in their country, drawing on the legislation and funding focus and using local data to predict how the future will unfold for STEM education.

Introduction

There is very little doubt that innovation in science, mathematics, engineering and technology have made considerable contributions to the world

> *Advances in STEM have already brought about improvements in many aspects of life, such as health, agriculture, infrastructure and renewable energy. STEM education is also key for preparing students for the world of work, enabling entry into in-demand STEM careers of tomorrow* (United Nations Educational Scientific and Cultural Organisation, 2017, p. 14).

In a world with increasing critical issues in the fields of agriculture, energy, medicine and the environment, STEM and STEM education continues to be seen as pivotal to developing creative solutions. Andrews (2015) speculates the rhetoric around STEM jobs translates to 'jobs for the future' and the World Economic Forum (2016) determines that STEM literacy is a measure of the future-readiness of countries. The reported growth in STEM-related jobs to be 1.5 times the growth rate of other jobs (14% compared to 9%) between 2006 and 2011 (Timms, Moyle, Weldon, & Mitchel, 2018). It has been recognised that STEM education can be a powerful force in creating innovative and creative thinkers with agile problem-solving skills who are shaping up to be informed and empowered citizens. Is it then the solution that we require or do we require a more holistic approach that includes skills and is not limited to

STEM subjects to prepare students for an innovative and uncertain future (Kärkkäinen &Vincent-Lancrin, 2013.

It would seem pertinent, then, to look to STEM educators and ask them to pause and reflect on the STEM education data available in their country and to assess the big picture and progress to date of STEM education. Researchers were asked to consider some key aspects of STEM, including the current focus, through their local literature, the legislation and where funding is currently being spent. More specifically they were asked to focus on their country and consider the following questions:

1. How is STEM/S.T.E.M currently viewed?
2. What funding and legislation currently have a direct impact on the teaching and learning of STEM?
3. From the available data, what might be the future of STEM?

STEM education in Australia

Current health of STEM education

The focus on time and energy devoted to STEM education in Australia reflects the “political reactionism to the potential deposition of the United States of America’s global superiority” (Blackley & Howell, 2015, p. 102). As such, it has taken quite some time to find valid educative reasons for such a heavy focus on STEM education in the compulsory years of schooling. Whilst STEM-based employment in Australia is projected to grow at almost twice the rate of other occupations, in 2012, a survey conducted by the Australian Industry Group (Ai Group) indicated that 41% of employers were having difficulty recruiting STEM-skilled technicians, and 26% were struggling to recruit STEM-skilled professionals and managers (Office of the Chief Scientist, 2014). The Ai Group Chief Executive, Innes Willox, noted that:

> *“STEM skills are essential for the future economic and social well-being of the nation … despite this, enrolments and the number of graduates with STEM qualifications continue to decline. This is a major concern for industry”* (Ai Group, as cited in Office of the Chief Scientist, 2014, p. 2).

Of further concern are the trends in Australia’s National Assessment Program Literacy and Numeracy (NAPLAN) numeracy results. Masters (2017) examined the NAPLAN numeracy trends for Years 3, 7, and 9 from 2008 to 2016 and noted that there was no significant change in national mean numeracy levels – the line graphs were essentially flat – with the exception of Year 5, showing an increase of 17 points. In addition, in 2015 the Programme for International Student Assessment (PISA), a triennial international survey that aims to evaluate education systems in Organisation for Economic Co-Operation and Development (OECD) countries by testing the skills and knowledge of 15-year-old students, had a main focus on science, with subsidiary minor areas of mathematics and collaborative problem solving and reading. Australia’s performance, whilst better than the OECD averages (17 points higher in science and 4 points higher in mathematics), has a decline in both science and mathematics since 2008. In fact, the change in science performance between 2006 and 2015 shows one of the strongest decreases among participating countries at drop of 6 points PISA Score and ranked 21 out of 28 (OECD, n.d.).

This is similar to the Trends in the International Mathematics and Science Study (TIMSS), an international comparative study of student achievement directed by the International

Association for the Evaluation of Educational Achievement (IEA), in 2015, testing Year 4 and Year 8 students in mathematics and science achievement, and asked questions about their background and experiences in learning mathematics and science at school. In Year 4 mathematics, Australia was outperformed by 21 other countries – and the scores are the same as for the last three cycles of the testing (at 516), with 30% of Year 4 students achieving at or below the “Low” benchmark (Thomson, Wernert, O’Grady, & Rodrigues, 2017). In Year 8 mathematics, Australia was significantly outperformed by 12 other countries. The 2015 score is not significantly different from the corresponding score in 1995 (Thompson et al., 2017), and 36% of students failed to achieve the “Intermediate” benchmark, which is the proficient standard for Australia.

In Year 4 science, Australian students were outperformed by 17 other countries, and the score is not significantly different to that of TIMSS 1995 (at 524). Similarly, in Year 8 science, Australia was outperformed by 14 other countries and the score is not significantly different to that of TIMSS 1995 (at 512) (Thomson et al., 2017), while only 7% of Australian Year 8 students achieved the “Advanced” international benchmark in science. Whilst cynics may suggest that the extra push for STEM education has apparently reaped no rewards in terms of national and international testing regimes, others would argue the need for an even stronger focus on STEM education to ensure improvement.

The 2015 TIMSS data in regards to students’ attitudes, engagement and aspirations indicate that Australian students generally reported quite negative attitudes towards mathematics, particularly in Year 8 (Thomson et al., 2017), with 27% of Year 4 and 50% of Year 8 students reported that they *do not like learning mathematics*, while 12% of Year 4 students and 29% of Year 8 students reported that they *do not like learning science.* There appears to be a decline in Australian students’ commitment to science and mathematics between the middle primary and lower secondary years, which may be contingent upon the pedagogical practices used by teachers – particularly those who are teaching out-of-field. In Australia, the amount of teaching out-of-field in science and mathematics in secondary school is especially high in comparison with other countries (Marginson, Tytler, Freeman, & Roberts, 2013). As Blackley and Howell (2015) noted, there is an ongoing challenge to teach authentic integrated STEM education in primary schools, with many teachers reverting to S.T.M. as a fall-back position. *Engineering* does not garner any of the spotlight, while *technology* is often relegated to the use of ICTs – a state of play that is supported by the perceived importance of NAPLAN, PISA and TIMSS results.

In addition, many higher education degrees have dropped STEM pre-requisites, even for STEM-related courses and professional pathways, which has in turn acted as a further disincentive for students to study STEM subjects in senior secondary school years. In turn, this has contributed to a decline in the number of teachers with STEM qualifications, thus completing the cycle of capacity gaps in STEM teaching.

Imagining the future of STEM

Despite our mediocre international performance in PISA and TIMSS, the Commonwealth and State governments of Australia continue to fund STEM initiatives that include teacher professional learning and the development of classroom-ready resources. In December 2015, the Australian Commonwealth government announced a National Innovation and Science Agenda with the mantra to “inspire all Australians – from pre-schoolers to the broader community – to engage with STEM” (Australian Government, 2018, para. 4), with an investment of $1.1 billion over four years. This funding reaches early childhood to mid-career researchers: from Early Learning STEM Australia (ELSA), a play-based digital learning program for children in pre-school inclusive of $14 million for play-based learning applications, and science and mathematics resources for Early Childhood educators, to the creation of a new Prime Minister's Prize for Science ($250 000), the Prize for New Innovators which was awarded for the first time in 2016.

Under the National Innovation and Science Agenda's *Inspiring all Australians in Digital Literacy and STEM* measure, a variety of new initiatives will be introduced to increase the participation of all students and the wider community in science, technology, engineering, and mathematics and to improve their digital literacy. The total funding for this program is $112.2 million. In addition, the Department of Education and Training's initiatives – *Inspiring STEM Literacy* and *Embracing the Digital Age* has a total funding of $64.6 million. The government is providing significant funding to support a range of education projects to improve STEM outcomes for school students. This includes: $51 million under the *Embracing the Digital Age* measure of the National Innovation and Science Agenda; $12 million under the *Restoring the Focus on STEM* measure of the Industry Innovation and Competitiveness Agenda; and $5 million under the Australian Maths and Science Participation Program (Australian Government, 2018). Unfortunately, this has seen $4 billion dollars taken from all areas of tertiary.

In summary, the state of play in Australia is that STEM education is still being heavily funded and spotlighted by the Commonwealth and State governments. However, as indicated by the NAPLAN, PISA and TIMSS trend data, student performance in science and mathematics in the compulsory years of schooling has flat-lined, showing no significant improvement over the last eight years. What one needs to bear in mind is that there is no conclusive evidence that STEM education is beneficial in terms of encouraging more students to take STEM subjects in senior secondary school or to select STEM-related degrees or career paths, and apparently, from these data, STEM education does not improve student achievement or attitudes toward science and mathematics in schools.

STEM education in Indonesia

The Indonesian archipelago, made up of around 17,500 islands, is located in Southeast Asia and lies along the equator between the Indian and Pacific Oceans. Along with its geographical and cultural diversity it shares different values and practices from more than 300 ethnic groups (Blackley, Rahmawati, Fitriani, Sheffield, & Koul, 2018). Today, Indonesia faces many challenges as the world's fourth most populated country with 43% of its 250 million inhabitants under the age of 25 (OECD, 2016). This current demographic situation has led to a rapidly changing age structure, with the possible advantage of what is referred to as a "demographic dividend" (Hayes & Setyonaluri, 2015, p. 1), a condition that can provide a powerful stimulus to economic growth and family welfare. Indonesia has had strong and stable growth over the past two decades with gross domestic product (GDP) growth rates above 5% annually despite the challenges of investment, commodity prices, infrastructure, air pollution, deforestation and the depletion of its natural resources (OECD, 2016). The Indonesian economy relies on natural resources; however, science and technology play an increasingly important role in continued growth and development (Hayes & Setyonaluri, 2015).

Current health of STEM education

The 2017 Global Human Capital report ranks Indonesia at 65 out of 130 countries based on the four thematic dimensions of capacity, deployment, development, and know-how (World

Economic Forum [WEF], 2017). In addition to the above ranking, recent data from Statistics Indonesia (Statistics Indonesia [BPS], 2018) shows that the unemployment rate fell to 5.5% of the nation's labour force. Within this environment, the 2005-2025 Indonesia Science and Technology Statement sets out a shared vision for improving Indonesia's global competitiveness and for fostering its transition toward a knowledge-based economy (OECD, 2016). The current government policy emphasises the role of science and technology for achieving national economic development aims. Therefore, research and education are focused on science and technology in order to align with the government policy and to achieve national goals.

All school types and levels in Indonesia employ a national standards-based system, which guides the educational process (Law of the Republic of Indonesia Number 20 Year 2003). Both the development of school curricula and the national assessment system are based on these standards. The importance of science and mathematics is exemplified through current curriculum reform that is focused on the development of scientific inquiry and literacy. Along with language, science and mathematics are considered the most important foundation subjects in schools and are tested through the government-administered National Examination. Currently, however, in large-scale international comparative studies such as TIMSS and PISA, the ranks of Indonesian students’ scores are still low.

Science and mathematics are considered important in Indonesian secondary schools where only Year 10 students with a good academic standing can enrol in the science pathway. Eligibility to enrol in the science pathway is competitive as it is one of the pre-requisites for university admission in science-related subjects such as medicine and engineering. These subjects, and the occupations related to them, are regarded highly in society.

Challenges to implementation

In education, STEM has been integrated into the curriculum using a holistic approach to teach students to analyse and solve problems by using technology and collaborative learning strategies. However, developed and developing countries, including Indonesia, face challenges in improving STEM education (Caprile, Palmen, Sanz, & Dente, 2015). In Indonesia, STEM is taught separately in science and mathematics lessons. Although these subjects are considered important and are highly valued, STEM as an integrated subject itself is not yet well developed. STEM can be seen as the integration of subjects through a paradigm shift focused on mathematics and ICT literacy development. Therefore, to successfully integrate STEM into the curriculum, an adjustment will be required.

Curriculum 2013 has resulted in the integration of technology into all subjects including science and mathematics (Ministry of Education and Culture, 2016). In the current curriculum, a thematic approach has been used at the elementary school level, while in secondary school, science and mathematics are separate subjects. However, challenges for implementing a STEM approach remain in both educational settings. In elementary school, students learn through a thematic approach, but the assessments are still based on separate subjects. In secondary school, where the focus is on content knowledge, implementing STEM education through subject integration and a paradigm shift is challenged by time limitations, teachers' competencies and the overly packed curriculum. In this context, it is more challenging to implement a STEM approach as an integrated subject than as a paradigm shift within the existing curriculum.

In vocational schools (Secondary Vocational School [SMK]) there is a focus on developing skilful graduates for the workforce where the implementation of STEM subjects has been integrated into classroom activities. The government emphasis on the SMK approach is to achieve national development objectives, solve unemployment problems and provide an opportunity for the future development of STEM education in vocational schools.

Progressive development in STEM has occurred in higher education since the emphasis on science and technology development was aligned to government policies. The Indonesia Higher education institutions invest significant funding in conducting science and technology research and encourage-multi-disciplinary research. Research in higher education is expected to contribute to Indonesia’s science and technology development. The Ministry of Research, Technology, and Higher Education is focused on developing global *Industri 4.0* skills to be integrated with the higher education curricula in support of a STEM approach (Ministry of Research, Technology and Higher Education, 2015). The ministry also encourages universities to create study programs in STEM subjects to continuously develop university graduates' employability skills to meet global competitiveness challenges, including within the Association of Southeast Asian Nations (ASEAN) economic community (Ministry of Research, Technology and Higher Education, 2015).

Indonesia spends 20% of government expenditure in the education sector, however, the impact on education quality is still questionable. Therefore, the government is concerned ~~on~~ with several aspects in education, including the role of teaching and research in improving education quality. Even though there is investment in STEM in higher education, the use of research results for improving STEM education need to be evaluated and reflected in national policy. In addition, teacher competencies development is important for improving the quality of STEM education.

Imagining the future of STEM

In Indonesia, STEM research projects are becoming more evident as indicated by the increased emphasis on research in national and international seminars, and provision of both private and government research grants in STEM topics. STEM research projects have been conducted in primary and secondary schools, including:

- projects focusing on multiple intelligences approach (Suwarma, 2014), student attitude (Suprapto, 2016), and scientific literacy (Afriana, Permanasari, & Fitriani, 2016),
- projects related to learning resources used a virtual laboratory for junior high school students (Ismail, Permanasari, & Setiawan, 2016) and STEM learning materials for physics in secondary schools (Pangesti, Yulianti, & Sugianto, 2017; Pertiwi, Abdurrahman, & Rosidin, 2017),
- performance assessment in STEM (Septiani & Rustaman, 2017),
- integration of art in STEM education conducted through STEAM education in chemistry learning for 21st-century learning skills (Hadinugrahaningsih, Rahmawati, & Ridwan, 2017),
- STEM and disaster (Sampurno, Sari, & Wijaya, 2015),
- STEM education in chemistry (Firman, 2016; Wisudawati, 2018),
- A makerspace approach to STEM learning in elementary schools (Blackley, Rahmawati, Fitriani, Sheffield, & Koul, 2018).

STEM education is a global movement in response to global challenges. Based on the condition of STEM education in Indonesia, challenges concerning curriculum integration, teacher competencies, pedagogy, assessment and student achievement need to be addressed.

Meanwhile, STEM education could be developed further through a curriculum focused on scientific inquiry and 21stcentury skills, educational expenditure, and higher education policy. In addition to the existing Indonesia national qualification framework (the Indonesian National Qualification Framework [KKNI]) a multi-disciplinary approach will become an important consideration for the future of STEM education in Indonesia (Ministry of Research, Technology and Higher Education, 2015). STEM education should be implemented in all Indonesian education settings, not only for workplace requirements and global competitiveness, but also for its moral and ethical values in enabling society to face the complexities of social life in the globalised world.

STEM education in India

India has about 260 million children enrolled in more than 1.5 million schools and is serviced by approximately 80 million teachers (National University of Educational Planning and Administration, 2015). There is enormous scope for this huge population to contribute to the future of the country, however the potential of this huge population is currently under realised, as indicated by the Organisation for Economic Co-operation and Development (OECD) test, where India ranked 72nd out of 73 participating countries in the last PISA study (OECD, 2009). Thereafter, India has not participated in other international tests.

Current health of STEM education

Although, the education system in India is placing increasing emphasis on science and mathematics, neither engineering nor technology education is a part of the regular curriculum. (Ministry of Human Resource Development, 2016). The factors needing immediate attention for improving existing science and mathematics education in India include the availability of and access to basic infrastructure and scientific equipment, shortage of quality teachers, and provision of an updated (modern) curriculum – which needs immediate attention (Sarangapani, 2017). In addition, red tape in administration, academic and casual attitude of stakeholders are partly the cause of the declining quality standards of the Indian education system (National Policy on Education, 2016). A further issue is the high number of students opting not to study science at the senior secondary school level (Sarangapani, 2017). This is attributed to the lack of hands-on learning and opportunities to develop critical thinking through inquiry-based learning. According to the 2018 World Bank Report, despite putting policies in place, overall science and mathematics competencies of Indian students at various levels of schooling is reported to be well below OECD standards. A mushrooming practice of after-school coaching through private providers is an indicator of the poor and limited educational practices in schools.

The Department of Education and Literacy was established soon after independence in 1947 with the aim of establishing educational facilities nationally. The National Policy on Education, which was formulated in 1968, and later modified in 1986 and 1992, recognises education as a precondition for development focusing on equity, accessibility and quality. The latest National Policy on Education (2016) identifies education as the most important tool for social, economic and cultural transformation and emphasises innovation, critical thinking and skills development. Furthermore, the policy identifies four essential components: building values, awareness, knowledge and skills that enable citizens to be skilled and competent, and to contribute to the nation’s well-being, to strengthen democracy and to foster social cohesion (Ministry of Human Resource Development, 2016). India’s Scientific Policy Resolution (SPR) of 1958 also resolves to foster, promote and sustain the cultivation of science and scientific research in all aspects. Science, technology and innovation have been identified as the drivers for India's faster, sustainable and inclusive growth (Government of India, 2013).

STEM school programs

The Indian government is working hard to foster positive attitudes to science among school students. Some of the science and technology programs for school students are as follows:

1. *Connected Learning Initiative* (*CLIx;* https://clix.tiss.edu/)
   This is the first initiative undertaken by The Tata Trust in collaboration with the Massachusetts Institute of Technology (MIT). CLIx is currently being implemented in four states – Chhattisgarh, Mizoram, Rajasthan and Telangana, where it is available to approximately 1,500,000 high school students and some 4,500 teachers in over 1,100 government schools.
2. *Atal Tinkering Laboratories:* With a vision to "cultivate one million children in India as Neoteric Innovators" (NITI Aayog, 2017, para. 1), the Atal Innovation Mission is establishing Atal Tinkering Laboratories (ATLs) in schools across India.
3. *Innovation in Science Pursuit for Inspired Research (INSPIRE):* The Department of Science and Technology (DST) developed INSPIRE, an innovative program in 2008 with the long-term foresight for attracting young students to a career in science. The INSPIRE Award targets approximately 200,000 school children every year in the age group of 10 to 15 years (National Innovation Foundation – India, 2018).
4. *National Children's Science Congress* (*NCSC;* http://www.ncsc.co.in/)*:* The seeds of the program for children's science congress (NCSC) has been conducted for the last 21 years. About 650 projects come to the national level every year from all over the country to participate in NCSC.
5. *The Initiative for Research and Innovation in Science (IRIS;* http://www.irisnationalfair.org/*)*:This program, initiated in 2006, is designed to popularise STEM and the spirit of innovation among students from Year 5 to Year 12. IRIS is an example of a public–private partnership initiated by Intel Technology India Private Ltd (Intel) with the DST, and the Indo–US Science and Technology Forum (IUSSTF).
6. *Science Express (*http://www.sciencexpress.in/): The Science Express is a mobile science exhibition for children mounted on a train which travels across India. The project was launched in 2007 at New Delhi by the DST. Although open for all, the project primarily focuses on students and teachers. The exhibition, now in its eighth phase, has travelled 142,000 kilometres and stopped at 455 stations altogether.
7. *Science Exhibition:* With a view to encourage, popularise and instil positive attitudes to science among Indian children since 1971 NCERT has organised a national science exhibition every year, where children can showcase their talents in science and mathematics, and their application to everyday life (National Council of Educational Research and Training [NCERT], 2018).

Imagining the future of STEM

India currently spends around 3.5% of its GDP on education (Ministry of Human Resource Development, 2016) as against the recommended 6% of GDP as the minimum expenditure on education and 0.88% of its GDP towards research and development (R&D; Department of Science and Technology, 2013). The Indian prime minister has indicated science, technology and innovation as the key to the progress and prosperity of India. He has asked the officials to draw up clear goals to identify the brightest and best science talent among school students and effective mechanisms to be made to increase engagement through the intervention of Science and Technology (S&T) by 2022, the 75th year of independence (Modi, 2017). He also announced a package of Rs 100 billion (approximately AUD $ 2 Billion) to transform 20 Indian universities into world class institutions.

The Government of India is trying to introduce constructivist teaching and learning theory by spending a major part of its research budget on STEM programs for school students. There is no doubt that many programs are being implemented on a large scale like the NCSC, Science Express and INSPIRE; and that they appear to be supporting an increased awareness about science and science-related career options. Their impact on supporting a constructivist approach, however, has yet to be examined. The shortcomings of these STEM programs, however, include a focus on the top 1% of students identified from National testing which leaves behind the majority of the students. These top students are also selected for various earmarked science competition programs. This approach does not provide opportunities for the less competent or disadvantaged students.

The limited contribution of the private sector in Research and Development (R&D) as percentage of GDP drags behind the desire of the government of India to invest 2% of its GDP on R&D (Press Information Bureau, 2014).

STEM education in the United States of America

The National Science Foundation in the USA introduced the acronym of STEM (science, technology, engineering, and mathematics) in the late 1990s (Blackley & Howell, 2015). The importance of STEM education in the USA is unquestioned. Government, industry, and the educational establishment all see STEM education as the pathway to innovation and as an essential element needed for the country to be at the forefront of economic prosperity in the world. However, the USA is not producing enough college graduates to fulfil the projected needs of industry.

Current health of STEM education

In 2010 President Obama’s Council of Advisors on Science and Technology found that “economic forecasts point to a need for producing, over the next decade, approximately one million more college graduates in STEM fields than expected under current assumptions” (President’s Council of Advisors on Science and Technology [PCAST], 2012, p. C7).

They also noted that:

> *Fewer than 40% of students who enter college intending to major in a STEM field complete a STEM degree. Merely increasing the retention of STEM majors from 40% to 50% would generate three-quarters of the targeted one million additional STEM degrees over the next decade* (PCAST, 2012, p. C7).

The natural question to ask is why so many students change their minds about pursuing STEM majors and what can be done about it. The report states:

> *The reasons students give for abandoning STEM majors point to the retention strategies that are needed. For example, high-performing students frequently cite uninspiring introductory courses as a factor in their choice to switch majors. And low-performing students with a high interest and aptitude in STEM careers often have difficulty with the math required in introductory STEM courses with little help provided by their universities. Moreover, many students, and particularly members of groups underrepresented in STEM fields, cite an unwelcoming atmosphere from faculty in STEM courses as a reason for their departure* (PCAST, 2012, p. i).

The report goes on to suggest that "Better teaching methods are needed by university faculty to make courses more inspiring, provide more help to students facing mathematical challenges, and to create an atmosphere of a community of STEM learners" (PCAST, 2012, p. i). This report advocates replacing standard laboratory courses with *discovery-based research* courses. Echoing that call for an active learning approach to STEM education in mathematics, a recent document from the Mathematical Association of America (Mathematical Association of America [MAA], 2018) stresses active engagement of students both in the classroom and outside. The MAA also suggests that mathematics departments foster community building in the classroom.

A meta-analysis of 225 studies on student performance in undergraduate STEM courses "indicate that average examination scores improved by about 6% in active learning sections, and that students in classes with traditional lecturing were 1.5 times more likely to fail than were students in classes with active learning" (Freeman et al., 2014, p. 8410). Evidence is accumulating that more than specific cognitive skills are needed by students to be successful in calculus and other demanding courses. Non-cognitive abilities such as perseverance, ability to work in groups, and self-concept are being seen as increasingly important (Gutman & Schoon, 2013).

The Mathematics Department at San Francisco State University, among mathematics departments at other universities, has initiated a program to provide an active learning environment to prepare underprepared students for entry level university STEM courses. In that program, called REAL (REvitalizing ALgebra), students study the traditional content of pre-calculus concepts and procedures by working in groups on challenging, non-routine problems. The group work is essential if students are to articulate their understandings.

Mathematical content is brought out when students present the solutions of the problems to the class and question each other's approaches. Community building is needed so that all students are comfortable talking to their group members and in front of the entire class. In this vein, each time new groups are formed, students introduce themselves to the group by responding to a non-threatening prompt, such as '*What's one of you favourite eating places near campus?'* This helps them see their peers as less threatening and helps shy students to start talking.

The support of the other members during group work allows students to develop skills beyond procedures used in calculus. These skills include non-cognitive skills, reading and interpreting problems, creating their own mathematical models, and struggling through the hardest parts of problems.

The REAL program consists of two algebra courses and a pre-calculus course. The pre-calculus course is currently being field tested so there are no comparative statistics about the success of its graduates in calculus. However, the graduates of REAL algebra courses did outperform students using traditional curricula in follow-up mathematics courses and significantly more REAL graduates chose to enrol in calculus.

As more mathematics and science departments change their curricula, following guidelines of the MAA and science organisations, it is anticipated that more students entering college and wanting to become STEM majors will actually graduate from STEM fields. STEM education and education in general at the K-12 level is not following the same direction.

Imagining the future of STEM

K–12 education in the USA is affected by politics and by an infusion of funding. Politics comes into play because public K–12 education is controlled by elected local school boards and because significant funding is allocated to education districts from the federal government. Funds also comes from wealthy individuals, such as Bill Gates, the co-founder of Microsoft Corporation. Gates helped finance the *Common Core Standards for English and Mathematics* along with the tests for its implementation. In mathematics, the Common Core supplanted the standards developed by the National Council of Teachers of Mathematics (NCTM). The latter advocated affective goals and active learning, while the Common Core focuses on teaching content and processes without mentioning non-cognitive goals or any pedagogical methods. The effect of the Common Core with its emphasis on testing has diverted many K–12 teachers from following the NCTM Standards and the recommendations of the MAA noted above.

The emphasis on testing at the K–12 level may be ebbing. A number of states have withdrawn support for the testing part of the Common Core and Betsy DeVos, Secretary of Education in the Trump administration, is not a supporter of the Common Core. At the same time, DeVos is an advocate for charter schools, which are funded publicly but operate outside of school district guidelines. Many charter schools are for profit. It is unclear how their emergence will affect STEM education.

To summarise the situation in the USA, STEM education at the college level seems to be moving in a direction toward increasing STEM majors, while at the K–12 level the situation is uncertain.

Conclusion

The production of graduates with specialities in Science, Technology, Engineering and Mathematics has been described as a ‘STEM pipeline’ where students enter University as the beginning of the pipeline and leave the pipeline work ready at the end of their degree. Then as graduates they are ready to meet the scientific needs of the country in all the STEM subject areas. This analogy has been extended to include a pipeline in schools where secondary and primary students are engaged in one or more of the STEM subjects and then continue to pursue these subjects and then have a STEM career. This paper promotes that pre-service education and the pre-service teacher education program which creates teachers in STEM subjects is a natural progression of the STEM pipeline. This then produces STEM educators in primary and secondary school education who engage and support students to continue to study STEM subjects.

In conclusion, there is a consistent view across the countries that STEM has been identified by their respective governments as being highly significant to the economic and environmental future of their country. In all the countries discussed in this paper millions, and in some cases billions, of dollars have been allocated to promoting the STEM industry and also promoting STEM education. STEM education needs to be viewed more holistically not just limited to the tertiary education sector, which is responsible for preparing graduates for the future. STEM education, and the importance of creating highly competent STEM practitioners also extends into secondary and primary schooling. It is deemed that STEM is important to the future growth and development of each contributing country, and therefore, providing quality STEM education from early childhood to tertiary levels is important. Creating a strong STEM program from early childhood, through primary to secondary and then into tertiary is also important to create a society that is scientifically literate to understand the value of STEM for the future. How this can be achieved successfully is going to be challenging to determine – Is it the measure of TIMMS or PISA that determines success; or the economic growth of a country? Or is the connection between solving future problems and future economic security, and the science taught in the primary classroom too divergent through time to measure?

References

Afriana, J., Permanasari, A., & Fitriani, A. (2016). Project based learning integrated to stem to enhance elementary school's students scientific literacy. *Jurnal Pendidikan IPA Indonesia*, *5*(2), 261–267. Retrieved from https://doi.org/10.15294/jpii.v5i2.5493

Andrews, K. (2015). Jobs of the future: The known unknown. *Australasian Science*, *36*(7), 38.

Australian Government. (2018). *Inspiring all Australians in science, technology, engineering and mathematics.* Retrieved from https://www.innovation.gov.au/page/inspiring-nation-scientists

Australian Industry Group (2015). *Progressing STEM skills in Australia*. Retrieved from http://cdn.aigroup.com.au/Reports/2015/14571_STEM_Skills_Report_Final_-.pdf

Badan Pusat Statistik. (2018). *Tenaga Kerja*. Retrieved from https://www.bps.go.id/statictable/2016/04/05%2000:00:00/1911/penduduk-berumur-15-tahun-ke-atas-yang-bekerja-selama-seminggu-yang-lalu-menurut-status-pekerjaan-utama-dan-lapangan-pekerjaan-2008---2017.html

Blackley, S., & Howell, J. (2015). A STEM narrative: 15 years in the making. *Australian Journal of Teacher Education*, *40*(7), p. 102–112. Retrieved from http://dx.doi.org/10.14221/ajte.2015v40n7.8

Blackley, S., Rahmawati, Y., Fitriani, E., Sheffield, R., & Koul, R. (2018). Using a makerspace approach to engage Indonesian primary students with STEM. *Issues in Educational Research*, *28*(1), p. 18–42. Retrieved from http://www.iier.org.au/iier28/blackley.pdf

Caprile, M., Palmén, R., Sanz, P., & Dente, G. (2015). *Encouraging STEM studies for the labour market*. Retrieved from http://www.europarl.europa.eu/RegData/etudes/STUD/2015/542199/IPOL_STU(2015)542199_EN.pdf

Department of Science and Technology. (2013). *Research and development statistics at a glance 2011-12*. Retrieved from http://www.nstmis-dst.org/pdf/finalrndstatisticsataglance2011121.pdf

Firman, H. (2016). STEM Education is the Focus of Learning to Improve Environmental Resilience in the Era of the ASEAN Economic Community. In *Prosiding Seminar Nasional Kimia dan Pembelajarannya* (pp. 1–7). Malang, Indonesia: Universitas Negeri Malang.

Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences*, *111*(23), 8410–8415.

Government of India. (2013). *Science, Technology and Innovation Policy 2013*. Retrieved from http://www.dst.gov.in/sites/default/files/STI%20Policy%202013-English.pdf

Gutman, L. M., & Schoon, I. (2013). *The impact of non-cognitive skills on outcomes for young people: Literature review*. London, England: Institute of Education. Retrieved from https://educationendowmentfoundation.org.uk/public/files/Publications/EEF_Lit_Review_Non-CognitiveSkills.pdf

Hadinugrahaningsih, T., Rahmawati, Y., & Ridwan, A. (2017). Developing 21st century skills in chemistry classrooms: Opportunities and challenges of STEAM integration. *AIP Conference Proceedings*, *1868*. Retrieved from https://doi.org/10.1063/1.4995107

Hayes, A., & Setyonaluri, D. (2015). *Taking advantage of the demographic dividend in Indonesia: A brief introduction to theory and practice*. Jakarta, Indonesia: UNFPA

Ismail, I., Permanasari, A., & Setiawan, W. (2016). Stem virtual lab: An alternative practical media to enhance student's scientific literacy. *Jurnal Pendidikan IPA Indonesia*, *5*(2), 239–246. https://doi.org/10.15294/jpii.v5i2.5492

Kärkkäinen, K., & Vincent-Lancrin, S. (2013). *Sparking Innovation in STEM Education with Technology and Collaboration: A Case Study of the HP Catalyst Initiative*, OECD Education Working Papers, No. 91, OECD Publishing. http://dx.doi.org/10.1787/5k480sj9k442-en .

Ministry of Education and Culture. (2017). *JENDELA Pendidikan dan Kebudayaan, IX* (Maret). Retrieved from https://www.kemdikbud.go.id/main/uploads/default/documents/JENDELA_EDISI_ IX_2017.pdf

Ministry of Research, Technology and Higher Education. (2015). *Regulation of the Ministry of Research,* *Technology and Higher Education Number 44 Year 2015*. Retrieved from http://kopertis3.or.id/v2/wp-content/uploads/PERMENRISTEKDIKTI-NOMOR-44-TAHUN-2015-TENTANG-SNPT-SALINAN.pdf

Marginson, S., Tytler, R., Freeman, B., & Roberts, K. (2013). *STEM: country comparisons: International comparisons of science, technology, engineering and mathematics (STEM) education. Final report*. Melbourne, Australia: ACOLA.

Masters, G. N. (2017). How well are we learning from NAPLAN? *Teacher*, 27 April 2017. Retrieved from https://www.teachermagazine.com.au/columnists/geoff-masters/how-well-are-we-learning-from-naplan

Mathematical Association of America. (2018) *Instructional Practices Guide*, Washington, D.C.: MAA. Retrieved from https://www.dropbox.com/s/42oiptp46i0g2w2/MAA_IP_Guide_V1-2.pdf?dl=0

Ministry of Human Resource Development. (2016). *National policy on education 2016*. Retrieved from http://www.nuepa.org/New/download/NEP2016/ReportNEP.pdf

Modi, N. (2017). Science, technology innovation keys to India’s progress. *Business Standard*. Retrieved from https://www.business-standard.com/article/news-ani/science-technology-and-innovation-keys-to-india-s-progress-pm-modi-117071900779_1.html

National Council of Educational Research and Training. (2018). *Science Exhibition*. Retrieved from http://www.ncert.nic.in/programmes/science_exibition/index_science.html

National Innovation Foundation - India. (2018). *Inspire Awards - MANAK*. Retrieved from http://nif.org.in/inspire-awards

National University of Educational Planning and Administration. (2015). *School Education in India*. New Delhi, India: National University of Educational Planning and Administration. Retrieved from http://www.dise.in/Downloads/Publications/Documents/U-DISE-SchoolEducationInIndia-2014-15.pdf

NITI Aayog. (2017). *Application for Atal Tinkering Laboratories.* Retrieved from http://niti.gov.in/content/atal-tinkering-laboratories

Office of the Chief Scientist. (2014). *Australia’s STEM workforce: A survey of employers.* Retrieved from http://www.chiefscientist.gov.au/wp-content/uploads/DAE_OCS-Australias-STEM-Workforce_FINAL-REPORT.pdf

Organisation for Economic Co-Operation and Development. (2009). *Education at a Glance 2009.* Retrieved from http://www.oecd.org/education/skills-beyond-school/43636332.pdf

Organisation for Economic Co-Operation and Development. (2016). Indonesia. In *OECD Science, Technology and Innovation Outlook 2016*. Paris, France: OECD Publishing. Retrieved from https://doi.org/10.1787/sti_in_outlook-2016-66-en

Organisation for Economic Co-Operation and Development. (n.d.). *Australia Student Performance (PISA 2015)*. Retrieved from http://gpseducation.oecd.org/CountryProfile?plotter=h5&primaryCountry=AUS&treshold=10&topic=PI

Pangesti, K. I., Yulianti, D., & Sugianto. (2017). Bahan ajar berbasis STEM (Science, Technology, Engineering, and Mathematics) untuk meningkatkan penguasaan konsep siswa SMA. *Unnes Physics Education Journal*, *6*(3). Retrieved from https://journal.unnes.ac.id/sju/index.php/upej/article/view/19270

Pertiwi, R. S., Abdurrahman, & Rosidin, U. (2017). Efektivitas LKS STEM untuk melatih keterampilan berpikir kreatif siswa. *Jurnal Pembelajaran Fisika*, *1*(1), 11–19. (Translation in English??). Retrieved from http://jurnal.fkip.unila.ac.id/index.php/JPF/article/view/12095

President’s Council of Advisors on Science and Technology. (2012). *Engage to excel: Producing one million additional college graduates with degrees in Science,Technology, Engineering, and Mathematics*. Retrieved from https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/fact_sheet_final.pdf

Press Information Bureau. (2014, November 27). GDP in science research. Retrieved from http://pib.nic.in/newsite/PrintRelease.aspx?relid=112011

Sampurno, P. J., Sari, Y. A., & Wijaya, A. D. (2015). Integrating STEM (Science, Technology, Engineering, Mathematics) and Disaster (STEM-D) education for building students’ disaster literacy. *International Journal of Learning and Teaching*, *1*(1), 73–76. Retrieved from https://doi.org/10.18178/ijlt.1.1.73-76

Sarangapani, P. M. (2017). *Three challenges facing Indian school science education*. Retrieved from http://www.esocialsciences.org/eSS_essay/Science_education/Three%20Challenges%20Facing%20India_Sarangapani.pdf

Septiani, A., & Rustaman, N. Y. (2017). Implementation of performance assessment in STEM (Science, Technology, Engineering, Mathematics) education to detect science process skill. *Journal of Physics: Conference Series*, *9*, 3–10. http://iopscience.iop.org/article/10.1088/1742-6596/812/1/012052/pdf

Suprapto, N. (2016). Students’ attitudes towards STEM education: Voices from Indonesian junior high schools. *Journal of Turkish Science Education*, *13* (Special Issue), 75–87. Retrieved from https://doi.org/10.12973/tused.10172a

Suwarma, I. R. (2014). *A Research on STEM education theory and practices method in Japan and Indonesia* *using multiple intelligences approach* (Doctoral dissertation). Retrieved from http://jairo.nii.ac.jp/0063/00007768/en

Thomson, S., Wernert, N., O'Grady, E. J., & Rodrigues, S. (2017). *TIMSS 2015: Reporting Australia's results.* Retrieved from https://research.acer.edu.au/cgi/viewcontent.cgi?article=1002&context=timss_2015

Timms, M., Moyle, K., Weldon, P., & Mitchell, P. (2018). Challenges in STEM learning in Australian schools. *Policy Insights*, Issue 7. Camberwell, VIC: ACER.

Law of the Republic of Indonesia Number 20 Year 2003 on National Education System. Retrieved from http://kelembagaan.ristekdikti.go.id/wp-content/uploads/2016/08/UU_no_20_th_2003.pdf

United Nations Educational Scientific and Cultural Organisation. (2017). *Cracking the code: Girls' and women's education in science, technology, engineering and mathematics* (STEM). Paris, France: UNESCO.

Wisudawati, A. W. (2018). Science Technology Engineering and Mathematics (STEM) education approach against a microscopic representation skills in atom and molecule concept. *International Journal of Chemistry Education Research*, *2*, 2–6.

World Economic Forum. (2016). *The Human Capital Report 2016*. Retrieved from https://www.weforum.org/reports/thehuman-capital-report-2016 Challenges

World Economic Forum. (2017). *The Global Human Capital Report 2017*. Retrieved from https://weforum.ent.box.com/s/dari4dktg4jt2g9xo2o5pksjpatvawdb