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Susan Blackley
Curtin University

Jennifer Howell
Curtin University of Technology

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A Stem Narrative: 15 Years in the Making.

Susan Blackley
Jennifer Howell
Curtin University

Abstract: Since its inception in the late 1990s, STEM has continued to attract attention and sizeable funding in the US, UK, and Australia. This paper narrates the development of the STEM movement both nationally and internationally, and analyses both the influences that have progressed its evolution and those that have stymied authentic STEM practices. The pervading rhetoric of 'STEM crisis' is considered through a global lens, and is resolved as a geo-political phenomenon. The strident voice of the US in the STEM narrative is tempered by investigating the approach to STEM in European, Asian, and developing countries. Two perspectives are described in the narrative: the political and the educational. Each perspective has an apparently differing agenda that has resulted in little success in achieving the desired and much-publicised STEM outcomes. The paper concludes with suggestions of two courses of action that would most likely achieve the outcomes.

Introduction

Education and schooling constantly adjusts to changing political, social, economic and global contexts. Over the last decade, this phenomenon has been exemplified by the at times frenzied focus upon STEM (science, technology, engineering, and mathematics). This position paper seeks to examine the development of STEM, and will narrate an analysis of its rise, subsequent crisis points, and the impasse that has been reached.

The National Science Foundation conceived the notion of STEM in the late 1990s in the US. Initially the acronym was SMET but after negative feedback and some re-thinking it emerged as STEM (Sanders, 2009; Williams, 2011). In the US, the rhetoric about STEM is founded in *political reactionism* to the potential deposition of the US's global superiority. In the UK, the initial focus was on science, engineering and technology (SET), but by 2006 it had also become STEM. The UK's commitment to STEM is conceptualised in terms of human capital: "The best way for the UK to compete, in an era of globalisation, is to move into high-value goods, services and industries. An effective science and innovation system is vital to achieve this objective" (Sainsbury, 2007, p.3). The European Commission has been centrally focused on STEM policy since the 1990s. Asian countries with very high performing education systems and growing economies (such as Korea, Japan, China, and Taiwan) have established national policies around science and technology more broadly, and university and industry-driven research and development.

The Western STEM agenda has primarily been one of vocational and economic goals (Williams, 2011), funded by governments and promoted by politicians. Various economic imperatives were used to justify its importance, and shifts in workforce patterns or instances of economic downturns tended to result in an increased focus on STEM (Kuenzi, 2008; Williams, 2011). Interestingly, the current 'STEM crisis' resonates most in English-speaking countries (with the exception of Canada) and is based upon "quantitative indicators that show a declining relative (or even absolute) performance in international comparisons of achievement and a lower rank than the nation believes it should occupy; and/ or declines in participation in STEM subjects at school" (Marginson, Tytler, Freeman, & Roberts, 2013, p. 55). Several international organisations give significant attention to STEM issues which maintains a global focus. These organisations include the Organization for Economic Cooperation and Development (OECD), the World Bank, United Nations Science, Education and Cultural Organization (UNESCO), the European Union (EU), and the International Association of the Evaluation of Educational Achievement (IEA) (Marginson, et al., 2013).

It is important to note that whilst the concept of STEM would go on to be an impetus for educational reform, it was initially supported by academics and professionals in the four discrete discipline areas: science, technology, engineering, and mathematics. In tertiary settings, faculties were concerned primarily with increasing the numbers of student enrolments in their programs (Sanders, 2009). STEM has been much heralded as a solution or preventative measure to avoid economic downturns in the future, such as the Global Financial Crisis; however the basis for these assumptions does not appear to be based on any hard research (Williams, 2011), rather conjecture and speculation by political think-tanks. In the US and the UK during the early 2000s, uncoordinated STEM projects burgeoned and large amounts of money were spent (Kuenzi, 2008; Pitt, 2009). The somewhat naïve reasoning behind this was that in order to increase the pool of engineers and scientists, and to maintain global economic dominance, the spotlight must be focused upon improving education in the disciplines of science, technology, engineering, and mathematics: S.T.E.M. As such, it was developed from a rationale that was non-educational, and then foisted upon educators to enact.

The Narrative of Stem

The development of STEM will be presented as a narrative as this provides an opportunity to identify the main players in its creation and the crisis points that have impacted its evolution since its emergence in the late 1990s as indicated in Figure 1.

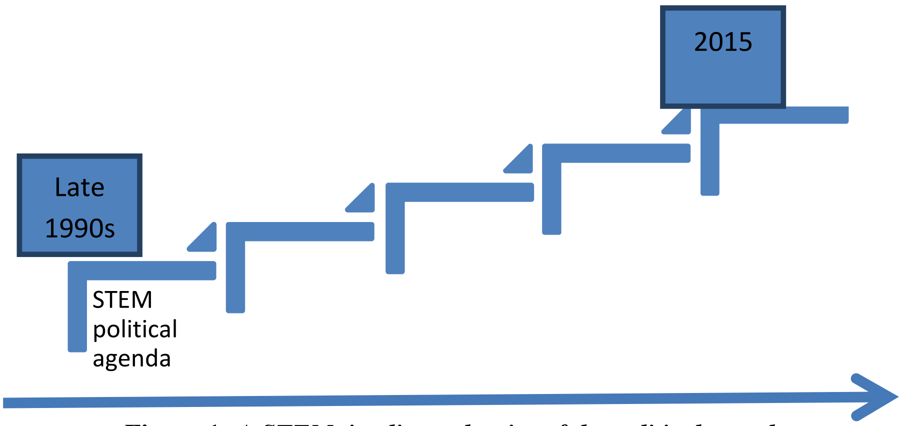

Figure 1: ***A STEM timeline – the rise of the political agenda***

As previously mentioned, the emergence of STEM was at the behest of a political agenda grounded in vocational and economic imperatives. The push from governments for increased numbers of students opting for STEM subjects in senior secondary and tertiary STEM related courses has been a challenge for educators (Office of the Chief Scientist, 2013). The struggle to enact the STEM agenda, particularly in primary schools, has not been resolved as teachers have defaulted to the notion of S.T.E.M. rather than STEM (Figure 2).

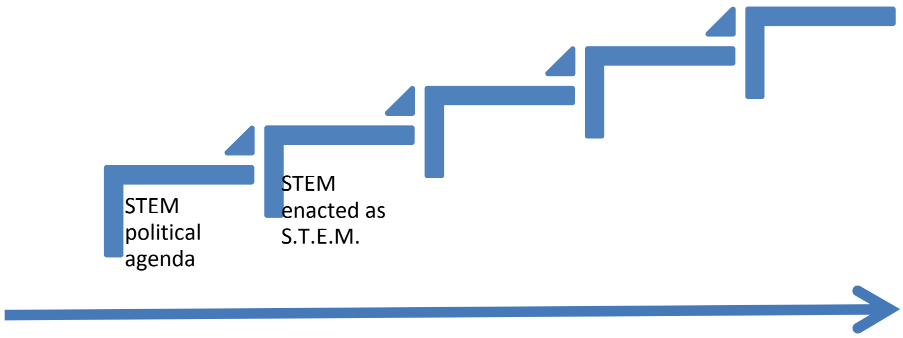

Figure 2: ***A STEM timeline - the struggle to enact STEM***

The inclusion of the full-stops is not trivial. It signifies and acknowledges the silo-ing of the four distinct discipline areas, rather than their integration. As Moore and Smith (2014) note “this separation is an artefact of history” (p. 7), and it will take more than a four-letter word to bring them together (Sanders, 2009).

The following are some of the STEM and S.T.E.M. issues that continue to plague educators. First, ‘engineering’ is not a subject area in the curriculum of either primary or secondary phases of schooling although there may be some evidence of its existence in aspects such as problem solving and innovation within subjects such as science and mathematics (Bybee, 2010), nor are pre-service teachers trained in the engineering discipline. Second, differing interpretations of the meaning of ‘technology’ led to confusion and frustration (Williams, 2011). Third, traditionally primary school teachers lack proficiency and confidence in teaching both science and mathematics, and instead favour the teaching of literacy (Ross, Beazley, & Collin, 2011). Fourth, as there is a paucity of mathematics and science trained secondary school teachers (Office of the Chief Scientist, 2013), many of those teachers timetabled onto lower secondary classes are teaching ‘out-of-field’ (e.g. they may be trained as Health & Physical Education specialists, yet are required to teach Year 8 mathematics). The amount of teaching out-of-field in science and mathematics is especially high in Australia by comparison with other countries (Marginson, et al., 2013). Arguably, this is a significant weakness of Australian education, “impairing both the breadth and depth of STEM learning” (Marginson, et al., 2013, p. 23) as secondary schools resort to employing replacement teachers who are under-qualified or unqualified in terms of science, mathematics, and technology. Underpinning these issues was the core challenge of trying to understand what STEM actually meant and what it looked liked enacted in the classroom. The acronym itself was easy to understand, but what it collectively represented was more challenging for schools to interpret and deliver in a meaningful way within the constraints of curricular imperatives.

The first two issues, the place and interpretation of ‘engineering’ and ‘technology’, resulted in a skewed interpretation of S.T.E.M., namely S.t.e.M. (Figure 3).

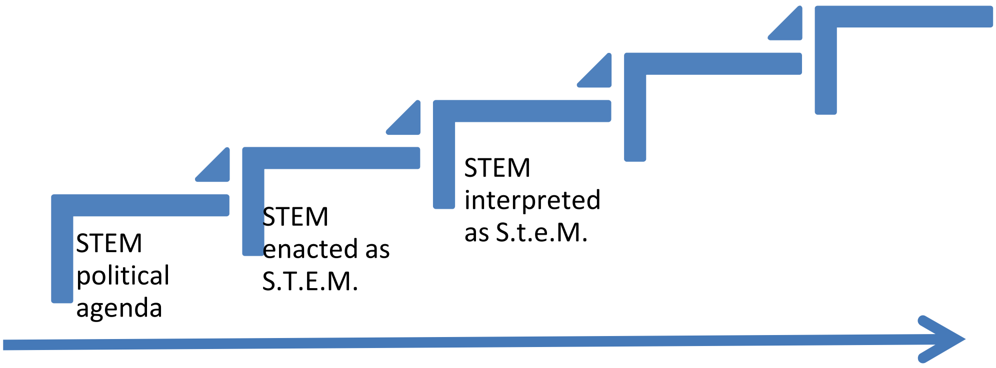

Figure 3: ***A STEM timeline - STEM interpreted as S.t.e.M.***

In other words, teachers focussed on the traditional teaching of science and mathematics and virtually ignored the technology and engineering components (Moore & Smith, 2014). The reason for this was the lack of curriculum documents to guide teachers through the teaching of these subjects, and the recent move towards embedding technology across the curriculum rather than being taught as a separate subject. There is also the ongoing polarising of the meaning of the actual term 'technology': some maintain that technology refers to the hardware and software with which one supports the teaching and learning process; whilst others view technology as the collection of tools, including machinery, modifications, arrangements and procedures used by humans. This confusion arises from two distinct subject areas in school curriculums, *information technology* (i.e. programming and computers) and *design technology* (i.e. machinery and processes).

In schools S.T.E.M. is enacted as S.t.e.M.; while outside schools (i.e. vocational settings) it is enacted as s.T.E.m. (Reiss & Holman, 2007). Science and mathematics are tools and frameworks for all types of engineering; in engineering one creatively applies scientific principles and uses mathematics to analyse and communicate observations. This discord between schools and vocational settings (Breiner, Johnson, Sheats Harkness, & Koehler, 2012) over the enactment of STEM and its meaning is the *first crisis point* in the STEM narrative. However the political agenda was aimed at increasing the number and retention of highly capable professionals in the engineering and technology fields, that is, a focus on technology and engineering which appears to support s.T.E.m. Yet the reality was that educators were focusing upon the subject areas of science and mathematics.

How then to bridge this divide within STEM?

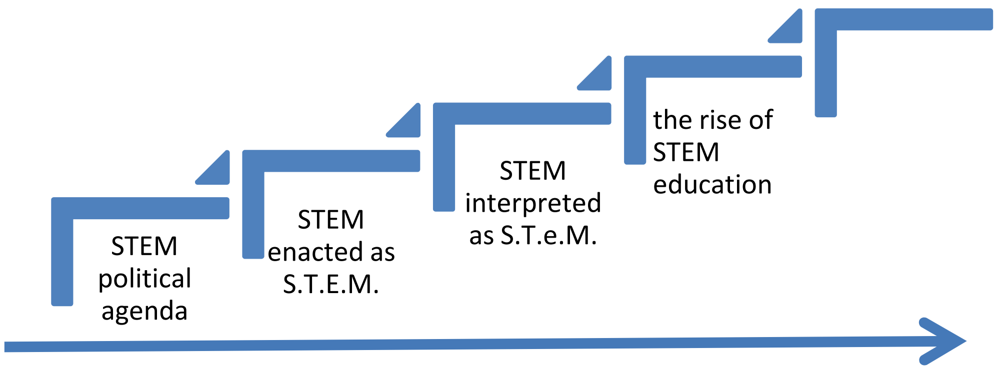

Figure 4: ***A STEM timeline - the rise of STEM education.***

Within this confused context arose the next chapter in the STEM narrative, with the education community recognising the potential pedagogical impact of STEM. As a result, ‘education’ was added to the name (Figure 4), thus making it “STEM education” (Breiner et al., 2012), perhaps to wrestle some of the ownership from the politicians as much as to highlight the role that educators have in bringing the political agenda to fruition. In part the failure of a focus upon STEM to enact any real change in schools was the absence of educators from the planning and strategising of the approach. The change in terminology to STEM education did not result in any meaningful modifications to teaching practices or student learning outcomes. The main strategy was to develop add-on programs or extension programs that were additional, although not always complementary, to routine school activities. Participation in these types of programs was not intended for all students; rather they were for self-nominated interested students or academically high-performing invitees. Despite energy and money being poured into STEM education, there was little measurable success (Breiner et al, 2012; Kuenzi, 2008).

This needs examining in further detail as it provides a clarity regarding the current situation for STEM and schools. Two key reasons for lack of success for STEM education as a concept to be implemented were (1) the curriculum structure, and (2) the skill level and/or preparation of the teachers. These two issues lie at the heart of why STEM initiatives have failed, and continue to fail, to achieve the expectations placed upon them. Currently in Australia there is a transition from state-based outcomes-based curriculums to a national curriculum. Teachers in schools have been grappling with enacting these changes, and in some states this has been a momentous event as they are also moving away from an outcomes-based approach to teaching and learning. However what has remained consistent in the suite of national curriculum documents is that the STEM discipline areas of science and mathematics have remained discrete subjects. There has been no attempt to either replace or offer as an alternative, an integrated STEM curriculum to support teachers. Without the provision of such a key curricular approach, and the continued high stakes national testing of numeracy skills via the National Assessment Program for Numeracy and Literacy (NAPLAN), the act of authentically teaching STEM in schools, as it is enacted in vocational and professional settings, is not going to happen. It would be a brave school in such a climate of accountability and comparison to step away from the separate curriculum silos to trial integrated STEM education.

The second issue is the skill level of teachers. Currently in initial teacher education programs there are discrete subjects that specifically cover two of the subject areas, science and mathematics (engineering is not included as there is no curriculum document for this subject, hence no imperative to teach it). Some institutions also offer a technology subject or attempt to integrate technology across all of the subjects in their course. Initial teacher education programs must meet national guidelines which set out the content and number of subjects that must be covered in order to achieve accreditation, hence only a minimum level of S.t.e.M. skills are being developed by graduate teachers. For initial teacher education courses to produce highly-skilled teachers of STEM change is required in the accreditation processes and guidelines setting out the scope of subjects and allocated credit points. Alternatively primary subject-specialists may be a solution to this problem; undergraduate programs could provide suites of electives to develop deep and broad knowledge and skills in one STEM subject. Another solution would be to consider changes to initial teacher education programs such as a move to postgraduate qualifications. This would require an undergraduate degree in one area, not necessarily limited to STEM subjects, and a substantial postgraduate teaching qualification such as a three year Master of Teaching, rather than the current one year Graduate Diploma of Education currently offered across Australia. For this to have any effect it would need to have the support of government, accreditation bodies, and tertiary institutions.

Associated with this second issue of teacher skills is the need to focus on teacher preparation programs. In-service primary school teachers would also need to be upskilled in STEM subjects, as their initial training would have been based on a general teaching model in which they were required to teach most of the subjects included in the curriculum. For these teachers to collude with this up-skilling there needs to be convincing evidence that increased time and effort in STEM education will result in improved student learning outcomes - at present none exists. Such a focus for teacher professional learning would perhaps need to be tied to their ongoing teacher registration as a motivator.

These two issues of curriculum structure, and the skill level and preparation of teachers, have led to *crisis point two*: whilst the education community has started to take some ownership of the agenda, governments continue to invest huge amounts of money in projects, and still the desired outcomes have not been forthcoming. Importantly, there is no consensus regarding STEM and how it is to be taught, for example as S.T.E.M, or s.T.E.m or other variations. There are declining numbers of students enrolling in these subjects in senior secondary schools (Goodrum, Druham, & Abbs, 2011), with the "broadening of curriculum offerings, students' self-perception of ability, and perceptions of subject difficulty and usefulness" (Kennedy, Lyons, & Quinn, 2014, p. 34) being possible reasons. There are declining results in the PISA scores (Programme for International Student Assessment) particularly in areas that focus on the application of STEM knowledge; and there is an apparent inability of primary school teachers to robustly teach all of the STEM subjects (Marginson et al., 2013). This is despite more than 14 years of STEM promotion and funding. This is a remarkable statistic and belies why STEM has persisted as a strategy.

The Rise of "Stem Education" – The Move towards Integration

Perhaps in an attempt to improve the situation, the education community subverted the political agenda by viewing the implementation of STEM education through a pedagogical lens, tempered by a growing appreciation of how the interplay of the four disciplines (science, technology, engineering, and mathematics) occurs in the world outside of schools. This may have been motivated by a number of reasons: an attempt to comprehend upon what the interest or push behind STEM might actually be based or an attempt to develop a viable approach for STEM implementation in response to the unrelenting push from government. Clearly STEM was going to continue to be a political priority, so a solution needed to be found.

Regardless of the motive, in 2007 this resulted in a significant re-naming: "STEM education" was now referred to as "integrated STEM education" (Figure 5).

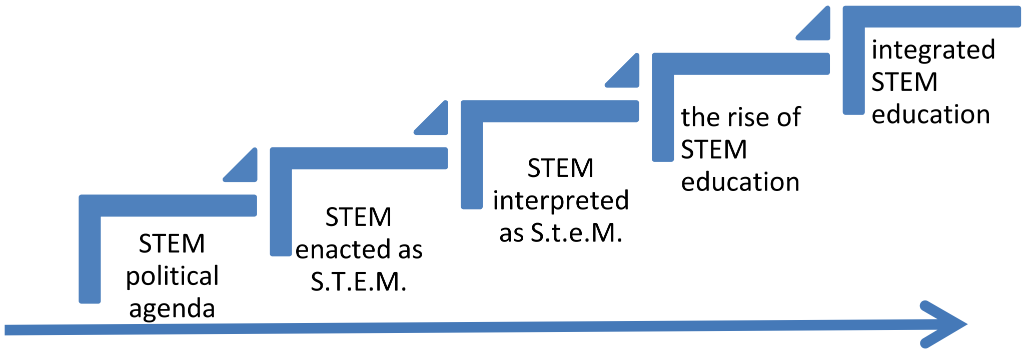

Figure 5: ***A STEM timeline - integrated STEM education.***

Sanders (2009) defined 'integrated STEM education' as teaching and learning between two or more STEM subjects or between a STEM subject and a non-STEM subject such as The Arts. He also described a pedagogical approach of "purposeful design and inquiry" (Sanders, 2009, p. 21) that combined technical design with scientific inquiry. The rationale for this was that in the world outside of schools, "design and scientific inquiry are routinely employed concurrently in the engineering of solutions to real-world problems (Sanders, 2009, p. 21).

Finally, a framework was emerging for teaching STEM. What was significant in this framework was the suggestion that integrated STEM education could be based on two or more STEM subjects; it was not suggesting that all *four* subjects needed to be included, and it suggested that subjects outside of the STEM suite could be involved. It was an integrated approach that was mindful of authentic, real-world applications of STEM. It was also a framework that was more manageable and logical from both a content and pedagogical perspective. The pedagogical approach of purposeful design and inquiry was strongly grounded in constructivism, using the pedagogies of inquiry and problem solving. The work by Sanders (2009) was the start of a logical approach to the implementation of STEM in schooling, soundly based on educational theory.

This early work was refined further by Moore and Smith (2014) who described two ways to 'integrate' STEM education:

1. Context integration – where engineering design is recognised as a *motivator* to teach mathematics and science discipline content, and
2. Content integration – where engineering skills are part of the learning objectives and mathematics and science content are *incidentally developed*.

As engineering skills do not form part of school curriculum learning objectives, *context* integration has been seen to be the method most likely to succeed in schools. The work of Moore and Smith (2014) addressed one of the key stumbling blocks to STEM education, how to include engineering.

The potential gains of employing a contextual integration approach to STEM education are significant. First, it supports a constructivist pedagogy, authentic learning, and student-centredness. Second, it can be seen as a "catalyst for helping teachers and learners out of their subject-based limitations into creative inter-disciplinarity" (Pitt, 2009, p. 42). Furthermore, such an approach provides opportunities for students to develop the 21st century skills of: adaptability, complex communication, social skills, non-routine problem solving, self-management, self-development, and systems thinking (Bellanca & Brandt, 2010). Perhaps this will achieve the previously unrealistic vocational goal of the political STEM agenda?

This brief narrative of STEM, its triggers and resulting crisis points has attempted to cover the ground from inception to the present day. It would appear that the move towards integrated STEM education and the emerging pedagogical frameworks is a step closer to achieving STEM in schools. This has been the narrative of STEM in Australia, it is important to briefly examine how STEM is addressed globally to contextualise this narrative.

The Development of Stem In Global Contexts

How has STEM been addressed globally? The literature reveals four geo-social realms that are characterised by distinctly different approaches to STEM: (1) English-speaking, (2) Western European countries, (3) Asian countries, and (4) developing countries. Globally, most of the efforts of governments, and most of the focus of media and public attention, has been in relation to STEM in schools: the curriculum, pedagogical approaches, teacher skill-levels, student motivation and subject selection. The STEM approach of the English-speaking countries is dominated by the US and UK, and is characterised by widespread talk of a 'STEM crisis'. There are a number of Western European countries, such as France and Germany that have emphasised STEM for some time as part of the framing of national policy on education and industry; the focus in these countries has been on the apparent 'STEM shortage' rather than 'crisis'. Typically, these policies or strategies involve: "promotion of a positive image of science; increasing public knowledge of science; improving school-based mathematics and science (teaching and learning); and increasing interest and participation in school-based mathematics and science, tertiary STEM disciplines and the STEM workforce" (Marginson et al., 2013, p. 104). Of interest are the 2012 PISA results (OECD, 2014) for these four countries, presented in Table 1, as the preoccupation with the quantity and quality of STEM is often, though not always, linked to national results in comparative international tests of school student such as PISA and Trends in International Mathematics and Science Study (TIMSS). PISA does not just ascertain whether students can reproduce what they have learned; it also examines how well they can "extrapolate from what they have learned and apply that knowledge in unfamiliar settings, both in and outside of school" (OECD, 2014).

	Mathematics literacy performance	Science literacy performance
OECD average	494	501
US	481	498
UK	494	499
France	495	505
Germany	514	508

Table 1. 2012 PISA results for key English-speaking and Western European countries.

Germany's scores seem to indicate that its advanced manufacturing status, where engineering has a large presence, is foreshadowed by these results from their 15-year olds tested in the PISA regime. France's scores, whilst close to the OECD average, outperform both the US and UK, with apparently less legislature, expenditure or political posturing.

Asian countries, the third identified grouping, have very high performing education systems, as indicated by their TIMSS and PISA rankings, and growing economies (Korea, Japan, China, and Taiwan) with established national policies around science and technology more broadly, and research and development driven by universities and industry. Furthermore, strong STEM performing countries in Asia have meritocratic career structures that recognise excellence in teaching these subjects (Marginson et al., 2013). China (Shanghai) scored highest in both the mathematical and scientific literacy components of PISA 2012. The country's approaches to planning are long-term, and there is a broad and deep consensus, among both the general populace and the government, about the importance of STEM and the links to research and development. In these countries, the language about STEM is more confident; no 'crisis' is flagged, no decline observed, and there are few issues about teaching capacity. It is crucial to note the practices of these countries that result in their STEM superiority: policies focus on achievable quantitative benchmarks, comprehensive reform programs are in every schooling system, there is a common movement towards more student-centred, inquiry-based and problem-solving learning, and an emphasis on creativity. Furthermore, teachers are respected and STEM subject classes are taught by discipline-qualified teachers, teaching in the fields in which they were trained.

Finally, in the fourth group, developing countries with an emerging industrial base and/or low levels of education participation and supply of qualified teachers, such as Brazil and South Africa, STEM is addressed in terms of improving participation in basic education and developing a qualified teaching workforce (Marginson et al., 2013).

So what can be learned from this brief overview of the global STEM context? It would appear that triggers such as a 'perceived crisis' which result in the spending of vast sums of money on interventionist programs, as in the US and UK, and Australia who follows these nations, does not result in the desired outcomes. Australia needs to set realistic goals, small changes to existing systems, similar to those implemented in the Western European nations, which can result in desired outcomes in Engineering and Science. Systemic changes, like those adopted in Asian countries, should be the benchmark to which the nation aspires within a sensible and realistic timeframe. The global context offers different models of STEM and the different outcomes achieved. They provide us with historical hindsight that should inform policy development and reform.

Conclusions

There are many challenges that need to be overcome for integrated STEM education to succeed. When teachers and students are positioned in a regime of standardised testing (e.g. in the US, UK, and Australia), and the results of the tests impact upon school funding, school image, and teacher performance pay, priority will understandably be given to the subject areas that are being tested: mainly mathematics and literacy. The challenge is to reassure teachers that embracing integrated STEM education and preparation for standardised tests are not mutually exclusive. There is also a potentially high financial cost and work commitment to retraining teachers and adapting pre-service teacher education programs to prepare for the implementation of integrated STEM education. Perhaps one of the most difficult hurdles to overcome is the lack of proof-of-concept. There is no evidence of positive outcomes with which teachers can be enticed to take up integrated STEM education. Furthermore, such evidence will not even be available for at least 12 years after implementation – the time taken for a student to travel through their primary and secondary years of schooling.

Fifteen years of the STEM narrative sees the education community at an impasse (for example, see; Breiner, Johnson, Sheats Harkness & Koehler, 2012; Kennedy, Lyons & Quinn, 2014). A fork in the road confronts it: taking the left or the right path will shape the future. Basically there are only two courses of action that could support the successful metamorphosis of the STEM narrative: either the education community holds the pedagogical high-ground resulting in integrated STEM education (integration) OR the education community supports the original political agenda by shoring up the discrete discipline areas (concentration).

The first course of action is fraught with the challenges of integration already discussed. The second course of action will require: an immediate injection of significant and ongoing funds for in-service teacher professional learning and modifications to initial teacher education courses to strengthen the confidence and competence of the teachers in mathematics and science; the provision of high-quality resources in primary schools to support 'hard' sciences (such as physics and chemistry) as well as the 'soft' sciences (such as biology and earth science); and the development of subject-specialist teachers in primary schools for mathematics and science. We posit that the second course of action will become the reality, however this can be tempered by the development of a pedagogical framework that will achieve the best of both courses of action: integration AND concentration.

A final and perhaps provocative thought: should there be a scattergun approach from which all students will experience some STEM education – or could some students receive all of the focus on STEM education? It seems that the first scenario is what has been tried; maybe the latter is truly the way forward.

Additional reference would strengthen the validity of the discussion.

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