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Commentary

STEM Education in Australia: Impediments and Solutions in Achieving a STEM-Ready Workforce

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Abstract: Recent government and industry priorities have led to a call to raise the quality of STEM learning to meet the future needs of industry and workforce skills. In Australia, education jurisdictions have responded to this challenge. Consequently, education is now considered critical in developing the skills required to meet these future needs. However, several significant issues have hindered STEM education's advancement. These impediments if not resolved may impact Australia's future STEM workforce and subsequent economic prosperity. This paper seeks to address some of the key impediments identified within the research literature by making a series of recommendations that provide insight into possible improvement to help recalibrate future STEM education initiatives and support Australia's long-term economic growth.

Keywords: STEM education; STEM; STEM skills; integrated learning models; problem-based learning; teacher development; workforce planning; economic prosperity

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1. Introduction

Raising the quality of STEM (Science, Technology, Engineering and Mathematics) learning has in recent years become a priority of the Australian government [1]. Central to its rise in prominence has been the prompting by Australian government policy to make STEM a focus [2,3]. This endeavor has resulted in a growing demand for STEM-based skills and has seen a rise in STEM-related educational services. The Australian government has urged the nation to become "STEM ready" by providing "a sufficiently large pool of high-quality STEM graduates ready for employment in any sector of the Australian economy" [4] p. 13. As Stewart [5] p. 263 suggests that "every report points to the need for more of our population to be 'STEM ready', as more of the most basic jobs require facility with technology, and new jobs require much deeper understanding of science and technology than ever before."

Crucial within this push has been an alignment of government policy targeting Australia's future fiscal goals. These goals suggest that much of Australia's economic future is entwined with the development and implementation of STEM, with some raising the prospect of STEM being a possible cure-all to Australia's long term economic issues [2,6,7]. It is not surprising then, that STEM has become a matter of economic priority, considering that "75% per cent of the fastest growing occupations now requires STEM skills, with over 70 per cent of Australian employers identifying STEM employees as among the most innovative" [7] p. 4.

Accordingly, educational jurisdictions have also acknowledged the need to be STEM-ready [8,9]. Australia's educational community has taken significant responsibility to support achieving this national STEM priority. Educational sectors, school communities and researchers have responded by developing new and innovative classroom practices [10,11].

Essential to achieving a fully STEM-ready workforce, several key issues must be addressed inhibiting STEM education's progress to ensure any past remnants of indifference or somnolence are resolved. Therefore, the paper identifies some of the major impediments found within the research literature inhibiting STEM education's progress. The paper then provides a series of recommendations as possible solutions to help recalibrate the current impasses confronting STEM education with the goal of supporting Australia's long-term economic growth.

2. Impediments to STEM Learning

With the rapid advancement of STEM industries and its subsequent workforce needs since the 1980s, a growing necessity to educate and promote STEM learning has emerged. As this area of study has continued to evolve and grow, several questions and impediments retarding the development of STEM learning have surfaced and remain unresolved [12], inhibiting both STEM education and supply of a "STEM ready" workforce. While no singular issue seems to eclipse another, it is evident that a conflation of issues has contributed to the current sense of insouciance within STEM education.

2.1. A Contested Definition

A central issue hindering STEM education's development found in the literature is the common inconsistency and confusion over the contested definitions of both STEM [13,14] and STEM education [15]. The core of the inconsistency and confusion is the interchangeable and fungible use, and at times misuse, of the terms "STEM" and "STEM education" and, more recently, the terms "integrated STEM education" and "iSTEM" [16,17]. Although this confusion is best summarised by Sanders [14] when he suggests, "Most, even those in education, say 'STEM' when they should be saying 'STEM education'" p. 20, a credible argument to resolve the issue can be made through scrutinizing the ontological and epistemological relationships these terms have in relation to the four STEM disciplines. The terms STEM education, integrated STEM education and iSTEM imply a subtly different meaning, one that is connected to practices related to teaching, pedagogy and curriculum but is also woven within the time-period they emerged. To better understand the difference in terms requires an understanding of the context they were created. The early use of the acronym SMET in the 1980s evolved quickly into the term STEM. The emergence of STEM education occurred at a similar time but with an emphasis on pedagogy, accounting for the duality of use. As STEM education began to grow, questions surrounding the integration arose and so did the emergence of the terms integrated STEM education and iSTEM.

It would seem that a consolidation of meaning separating the term STEM and those associated with STEM education did not properly become a part of the STEM community's vernacular. Although, as the report by Price [7] *A Smart Move* asserts, there "is no universally agreed definition of what counts as STEM education or field of occupation" p. 14, an argument can be made to re-set this aspect of the STEM agenda to make the term useful in order to support the future discourse and discussion.

While the definition of both STEM and STEM education remain contested, some agreement has begun to emerge from within Australian government policy to inform this discussion. The Australian Chief Scientist's report, *Science, Technology, Engineering and Mathematics: Australia's Future* [18] refers to STEM as "a broad field of distinct and complementary approaches to knowledge" p. 34; the Australian Education Council [1] p. 5 considers STEM education in cross-disciplinary terms and proposes that it "is a term used to refer collectively to the teaching of disciplines within its umbrella—science, technology, engineering and mathematics—and also to a cross-disciplinary approach to teaching that increases student interest in STEM-related fields and improves students' problem solving and critical analysis skills".

The notion of cross-disciplinary approaches or models reflected in the Education Council's definition raises a series of new questions and issues relating to how STEM education should be taught and ultimately the type of skills these type of approaches foster and whether they are the skills required by a STEM-hungry workforce. The confusion over teaching models and subsequent skills highlights the lack of a universally agreed understanding. The first major question to be investigated is what are the skills deemed as necessary by both educationalist and industrialists?

2.2. Uncertainty of What STEM Skills Are Required

If the Australian education community is to supply a large enough pool of high-quality STEM graduates for its long-term economic needs, what are the necessary STEM skills required to ensure the country's future prosperity? The prevalence of broad references that exist, describing what are considered to be the necessary STEM skills, belie the confusion (see [18–20]).

The United States' National Science Board [20] has in part provided a background to this argument. They note that as many as 26 million jobs in the United States require significant STEM knowledge and skill with at least one field and suggest that both STEM knowledge and skills are critical to an extensive portion of the entire United States' workforce. They further suggest that STEM workers must demonstrate myriad characteristics and lists, among these, the ability to work both independently and in teams and a willingness to persist in solving hard problems. It listed the required STEM capabilities under the three umbrellas of (i) cognitive competencies, (ii) skills and (iii) abilities. They suggest that the cognitive competencies include knowledge of the STEM domains and that the skills and abilities required for the 21st century include problem-solving, technology design, programming, deductive and inductive reasoning, mathematical reasoning and facility with numbers.

These cognitive competencies of the STEM domains are found in curricula internationally [21]. The Australian curriculum prescribed for K-12 addresses STEM within the domains of Science, Mathematics and Technology, but also through the seven General Capabilities which include Literacy, Numeracy, Information and Communication Technology (ICT) capability, Personal and Social capability, Ethical Understanding, Inter-cultural Understanding and importantly Critical and Creative Thinking. Engineering is addressed within Design and Technology and often provides a context for STEM-rich activities [11]. These STEM skills are aligned with 21st century thinking, which places importance on knowledge, skills and tools, such as multi-modal information processing, coping with complexity, personal information management and literacy and high levels of inter-personal communication as well as flexibility of assessment [22].

Work undertaken by Orpwood et al. [23] further supports the idea of the need for 21st century skills. They suggest 21st century skills should "include the ability to reason in innovative and creative ways, to collaborate and communicate using new and emerging technologies, to adapt rapidly, to solve problems and take calculated risks, and to continue learning throughout one's lifetime" and that globally, there is a new skills race developing. Siekmann and Korbel [24] suggest it may be better to borrow from multiple skill sets. They regard STEM skills to be "primarily technical skills as distinct from higher-order thinking skills and social-emotional skills" p. 44. Because of the ambiguities surrounding the multiple interpretations within the community, they suggest that the term "STEM skills" not be used, but rather, that the specific skills be cited, for example, cognitive skills, foundational literacies or job-related technical skills.

STEM skills identified by employers' list higher-order cognitive skills and socio-emotional skills as the most important, perhaps suggesting that the education system needs to focus in these areas rather than on technical skills. The argument is that if foundational skills and cognitive skills are well developed, then technical skills can be acquired later. This position is supported by Siekmann and Korbel [24] p. 23, when describing occupation-specific STEM skills such as system analysis and evaluation, time management and interpersonal skills. They suggest these occupation-specific skills are accompanied by skills that are considered to be 'learned on the job' such as creative problem solving, design thinking and lifelong learning.

Similar to those skills identified by Siekmann and Korbel [24] and Carnevale and Desrochers [19], the STEM skills identified by employers often fall under the umbrella of what are commonly called 21st century Skills [25–27]. A distinct movement away from technical skills [20,23] affirms the change in perception of the altering needs of future economies and workforces. Carnevale and Desrochers [19] in their work add further to this argument when they note that the impact technology was having on the United States' economy was fueling a demand for different skills.

It is evident that a corpus of literature is suggesting a movement towards a new understanding of what skills are necessary and that 21st century skills are the vanguard of what is perceived as necessary. Crisp, however, takes this argument one step further and suggests something new: that 21st century skills be described in cross-disciplinary terms as ways of thinking, ways of working and tools for working and living in the world. Crisp's assertion is supported by Australia's Chief Scientist [28], who highlights the relationship between STEM knowledge and skills and the manner in which they are taught. The Chief Scientist emphasises this relationship and states "A STEM education does not merely impart content knowledge in these fields—it seeks to provide frameworks in which new problems can be tackled" p. 2.

Given that researchers, such as Orpwood et al. [23], posit that the skill set required is, as yet, "poorly defined and the role of education in preparing graduates for the workforce is largely under-researched" p. 17, there is an argument that further investigation is necessary to investigate what skill set is actually required. While there remains a lack of universal understanding and agreement on the required skills there is evidence to suggest that, in Australia at least, the change to 21st century skills has been identified and in part adopted within the education community [1,26]. The growing recognition of Crisp's suggestion to consider STEM skills in cross-disciplinary terms and the Chief Scientist's sentiment of drawing attention to the relationship between STEM skills and pedagogy provide a more than reasonable weight of argument to the discussion of how these 21st century STEM skills should be taught, particularly at a time when various cross-disciplinary teaching models have been mooted as best practice. Within these models, however, sit several pedagogical approaches that have in recent years have gained traction within STEM classrooms but remain contested as they are problem- or inquiry-based approaches.

2.3. Problem or Inquiry-Based Approaches in STEM Learning

There is growing acceptance within STEM learning that problem- or inquiry-based approaches should be incorporated into the repertoire of STEM pedagogical approaches used by STEM educators. A strong argument to this claim is made through the National Science Statement [2], highlighting the relationship between integration of the four STEM disciplines and the possible benefits of using problems or inquiry-based learning. This is further supported by the Commonwealth of Australia's Innovation and Creativity Report [3], which identifies problem-based and inquiry-based learning as possible pedagogical STEM practices. The acceptance of problem- or inquiry-based learning is provided by researchers such as Sanders [14], particularly where constructivist pedagogy is used. An extension to this argument has been the introduction of authentic and real-world [14] STEM applications that are embedded in inquiry and problem-based approaches [29]. Whilst there is growing support for the argument that problem-based or inquiry-based approaches are the preferred methods of teaching STEM education, there is a corpus of literature to suggest otherwise.

Although support exists for the use of real-world approaches [14], some researchers question the efficacy of problem or inquiry-based approaches that are the centre of constructivist pedagogy [30–32] and challenge the common consensus. Despite the demand over several decades for evidence supporting the superiority of problem-based approaches over others, there is still little evidence to support their use [30], let alone consider these approaches to be superior to other instructional models [33,34]. There is more than enough research evidence to question the benefits of discovery learning taught under the pretext of social or cognitive constructivism in lieu of other approaches.

An argument supporting the opposition of this type of instruction is found in the cognitive science literature, particularly in cognitive load theory (CLT) [35,36]. Central to the underpinnings of CLT are the limited resources available to the working memory. The working memory is responsible for executive cognitive functioning, in particular problem solving, and for supporting the transfer of new learning from the short-term to the long-term memory. When the working memory is compromised by too much information, the ability to solve problems and transfer memory is hindered. Pedagogical approaches that use problem-based learning require the learner to recall numerous memories—some relevant, some irrelevant—to help undertake the task. The recall of irrelevant information is mixed with the relevant, and the learner then sorts through what is necessary. The burden of this additional extraneous information negatively impacts the learning experience by creating an excessive and unwarranted cognitive load. Learning pedagogies that reduce cognitive load provide a greater efficiency of schema acquisition and problem-solving capabilities. There is added complexity when considering whether STEM learning should or should not adopt problem-based learning, in that STEM learning tasks often already require complex conceptual understanding. If these understandings are not automated, the learner may be under excessive cognitive load before the task has commenced as they attempt to recall all they know about the problem they have been given. This is not to suggest there are no benefits to using a problem-based approach when teaching STEM education, particularly if team building or collaborative learning is an anticipated outcome.

The challenge is to know when and why a problem-based approach should or should not be used.

2.4. Who Should Be Teaching STEM

Just as some apprehension is evident in the use of problem-based pedagogical approaches, questions about the training, formation and quality of teachers undertaking STEM education have been raised.

With the growing emphasis on improving STEM education, the question of what crucial support and training STEM teachers receive is important. This question is particularly critical considering STEM teachers are the key facilitators in the learning process, in that they ultimately making the arguably most important decisions in the STEM educative process—what pedagogical approach should be used. STEM teachers are the purveyors of knowledge and are the central players in helping governments meet national future employment goals. Research suggests that countries with a strong STEM educational culture have teachers that are afforded high levels of respect and esteem [3]. If STEM education is seen as critical to meeting national goals, teachers must be supported and trained appropriately.

A key element of this will be ensuring that teachers are fully qualified within their disciplines. STEM teachers need to be specifically trained in the various and appropriate STEM pedagogies and offered regular opportunities for professional formation. It also raises the further implication of whether teachers who have specific training in such an important area should be remunerated commensurate with the level of required expertise. Whether financial incentives would play a part in attracting the most desirable teachers may be open to debate, it may, however, attract those teachers with exceptional content knowledge in the STEM disciplines. Given that the question and issue of professional development has been raised in a number of government reports [1,4] it could be argued that there should be a mandated and a common nation-wide professional development approach aimed specifically at increasing the capacity, quality and depth of STEM teachers across the country. The burgeoning need to provide exceptional STEM teachers is heightened by the call to "ensure all students finish school with strong foundational knowledge in STEM and related skills" [1] p. 5.

One of the greatest dilemmas facing Australian and international schools is providing teachers who can teach in a STEM subject. One peculiarity in Australia, unlike other jurisdictions, is that teachers may teach outside their curriculum field of expertise. A teacher can teach a STEM discipline due to circumstances within the school even though they are not qualified to teach that discipline. To avoid this, consideration should be given to producing graduate teachers who are not only qualified to teach STEM subjects but also able to navigate the teaching of specific STEM pedagogies. The lack of STEM teaching expertise is emphasised within the Innovation and Creativity Report [3], which identifies the significant shortfalls in teacher capabilities and school resources, making it difficult to teach STEM education effectively.

Whilst a number of issues have also already been raised, a central question that remains unresolved is which approach, if any, should be given preference over another.

2.5. Contested Cross-Disciplinary STEM Pedagogies

A brief overview of the literature investigating how STEM education and corresponding skills should be taught suggests no clear indication of any particular approach and remains contested [17,37].

Major attempts have been undertaken to reform the manner in which STEM is taught. New approaches have adopted conventions and structures that have challenged previous teaching precedents, particularly in the adoption of incorporating the four STEM disciplines of Science, Technology, Engineering and Mathematics in some manner into one integrated discipline. While the integrating of Mathematics and Science was first recognised more than a 100 years ago [38] and with the more recent integration of the four STEM disciplines in the 1980s in the USA [39] having mixed results, an integrated approach to teaching the STEM disciplines has only recently become more palatable, emerging from the USA in 2007 [14]. Since the earlier false starts, the overall idea of integrated STEM learning has gained worldwide traction and continues to be well supported [15,40] both by government and educational communities.

Although a range of integrated STEM teaching models have emerged, no one model has become dominant or preferred over another. Models such as the Burrows and Slater [39] and the Vasquez et al. [41] offer some insight into possible STEM models. While a range of alternative models exist, these two are used in this paper as examples to offer some insight into resolving some of the issues raised. What is strikingly common with both models is the use of authentic and real-world applications of teaching STEM. They both endorse the use of problem-based learning, as supported by Sanders [14] and both support the recommendations in the Commonwealth of Australia's Innovation and Creativity Report [3] and National Science Statement [2]. However, what is common in too many models, including the two used as examples in this paper, is the integration of one or more STEM subjects (Science, Technology, Engineering and Mathematics), meeting the call by some for some level of integration [42,43].

The transition of these subjects into an integrative model, however, has not automatically amended the conceptual thinking underpinning the rationale of integrating STEM subjects. Researchers such as Herschbach [44] suggest that traditional school models continue to teach subjects separately and that there remains little consideration of any interrelation between the subjects, with their primary aim being simply to transmit a corpus of essential knowledge. It is evident that, whilst a groundswell of acceptance for some form of integrative STEM learning exists, there remains uncertainty about how it should be taught.

Whilst STEM education may be in its infancy when compared to other more developed subject areas, the call for further robust scholarship [38] and greater advocacy to investigate pedagogical approaches [17] may lead to solutions in the other areas that remain unresolved.

3. Discussion

This paper has highlighted a range of complex impediments that have emerged, hindering the progress of STEM education and impacting the advancement of Australia's STEM industries. Several solutions to resolve the current predicament are now proposed. The first to be discussed is the continued confusion over the terms used to describe STEM and STEM education. A simple solution is to implement a greater consistency of the language conventions used to describe STEM/STEM education/integrated STEM education/iSTEM. For this to be successful, terminology would need to be implemented at all levels of government, industry and academia and in broader educational communities. The consistency of language can help to mitigate the concerns and differences in meaning amongst stakeholders. A targeted campaign to qualify and clarify language conventions will help overcome what some commentators label as the worn-out usefulness and ambiguity of the term STEM education [45], as well as simply de-mystifying the shroud of confusion currently experienced by broader targeted audiences and the general community, which will aid in the public promulgation of STEM and STEM Education.

Concerns over the STEM skills deemed necessary also remains unresolved. Further discussion is required to clearly articulate what the government, industry and education identify as priority skills. It is evident that these skills differ, depending upon each respective perspective. The STEM skills within the workforce necessary to deal with industry demands are currently different to those identified in education. If education is to better serve the needs of industry and, indeed, to respond to the Education Council's aforementioned call to ensure that students finish school with strong foundational knowledge in STEM and related skills, then there clearly needs to be a united perspective as to what this means. Further investigation and a call to action in relation to agreeing as to what constitutes STEM skills and how they should be taught is urgently required. This is not something that can happen in isolation between parties. It requires all sectors to work cohesively with common goals established through a deep understanding of a national need which goes beyond the classroom and must be co-driven so that pedagogical principles are not lost within industry short-sightedness or fiscal restraint. It requires all parties to act in the national interest.

In resolving how Australia is to become fully STEM-ready, the continued exegesis of the various STEM teaching models is significant. Although a shortfall of this paper is that it highlights only two models, it is acknowledged that significant research is required to identify and critique many other STEM teaching models. The additional critiquing of other STEM teaching models could provide further insight into alternative pedagogical actions that may benefit and supplement the existing approaches. This could mean that at some point in the STEM learning process, multiple models are used concurrently with vacillating levels of integration between problem-based/project tasks or direct instruction dependent on the learning context.

While this suggests that there is no optimal model (or models), it may be that the investigation of the existing STEM models may lead to a paragon model of excellence, one that at a future point is a heuristic approach driven by the learner to learn independently and by themselves; this may supersede existing thinking and make current STEM teaching models redundant. Research in this area and the corpus of knowledge generated will not only inform educators about the most effective model to teach STEM but may well inform when not to use certain approaches.

A question that continues to remain contentious is in relation to the type and amount of integration that should occur. It is evident that the acceptance of one preferred integrative model, one that can be universally applied to every situation, context and condition, remains elusive. In many ways, a singular universal model is inappropriate, in large part due to the enormous differences in educational situations, system goals, curriculum design, students' learning needs and teachers' objectives. It is arguable that one model cannot accommodate all these and, therefore, there may be no single integrated model that can or should be preferred over another.

That said, the type and level of integration that should occur needs continued investigation. Informed research may in fact suggest situations where a non-integrated or silo teaching model, one that sees a STEM subject taught independently and as a separate entity, may be of some benefit. On the other hand, a level of interconnectedness and consequent interrelated connectivity may, in other circumstances, provide additional insight into exploring the benefits of authentic or real-life situations and provide understanding where using these problems may be more relevant.

Critical within the reforming of STEM education is the further investigation of problem- or inquiry-based learning with current STEM education practices. The importance of reviewing and adopting pedagogical approaches that are sympathetic to new cognitive understanding and cater for the cognitive load implications created by STEM learning may provide future breakthroughs to improve not only the current pedagogical approaches but also the current pedagogical teaching models.

Given that the teaching of STEM skills predominately falls within the bailiwick of education, a major consideration in any argument to improve STEM learning should involve the role that teachers play. Providing STEM educators with the right training and professional formation is paramount. What this is and what it looks like is complex and remains unresolved. Whether STEM education is best undertaken by high quality subject specialists operating within each STEM learning area (silo), or rather by being taught within a cross-disciplinary framework (integrated) and delivered by educators acting singly or in tandem requires further attention. It is not unreasonable to suggest that a blend of integrated and silo learning from many different teaching models might ultimately prove the most effective in finding the elusive teaching sweet spot, but educators must be trained to realise such an outcome.

As final point, it could also be argued that governments, both in Australia and internationally, could be calling for graduates of STEAM (Science, Technology, Engineering, Arts and Mathematics). This would acknowledge the importance of the Arts in fostering creative and critical thinking and may, by incorporating or subsuming it, aid in progressing the STEM education cause. It might also lead to the establishment of one or more "learning areas", such as TEM (Technology, Engineering and Mathematics) or even EM (Engineering and Mathematics), emerging as more necessary and important for future industry needs, which in turn would then direct the education roadmap away from both STEM and STEAM. Such areas could be the subject of future investigation and commentary as industry needs change and a better.

4. Conclusions

The main purpose of this paper was to identify the major impediments inhibiting the progression of STEM education. We argue that hindering the advancement of STEM education has an impact on a future Australian STEM workforce, which may lead to implications on Australia's long term economic prosperity. While we argue that there are a number of significant issues, several solutions do exist to help recalibrate the current impasses confronting STEM education. Key to resolving these issues is how the Australian government responds. If the Australian government is to ensure that a viable STEM-ready workforce is to exist into the future, it needs to invest now in the appropriate levels of resources for all key partners. It requires the cultivation of substantial partnerships with industry and education to develop a common mission, vision and core objectives. The somber countenance of the current geo-political situations, the fracturing of economies and the displacement of populations only adds further to the challenges facing governments worldwide. Any actions to support the advancement of STEM education will not only benefit Australia's future economic imperatives but may go some way to help resolve some of the greater issues of our time.

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