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Indigenous Australian STEM in K-12 Classrooms: A Narrative Literature Review

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ACKNOWLEDGEMENT OF COUNTRY

Whilst embedded in traditions and culture, Australian Indigenous people have always been at the forefront of innovative and communicative knowledge and skills, that have enabled them to thrive for over 40,000 years on this land we call Australia. Our First Nations people, the traditional owners of this land, are by definition, our first leaders in innovation.

In writing this paper, we acknowledge the Gadigal People of the Eora Nation as the Traditional Custodians of the Country where this report has been developed. We recognise their continuing connection to the land, and pay our respects to Indigenous Elders past and present. We recognise our emerging Elders, who will continue to carry this knowledge on this land long after us.

In preparing this paper, we would like to acknowledge our consultations with Indigenous STEM educators and leaders who shared their knowledge and experiences, and provided valuable insights for this report including Professor Chris Matthews, Chair of the Aboriginal and Torres Strait Islanders Mathematics Alliance (ATISMA) and Associate Dean (Indigenous Leadership and Engagement) at the University of Technology Sydney; Paul Byrne, Chairperson for the NSW Primary Principal's Association – Aboriginal Educational Reference Group; and Kim Dyball and Karlie Noon from CSIRO's Indigenous STEM Education Project. We sincerely thank them for their time and sharing their knowledge for the purposes of this research.

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EXECUTIVE SUMMARY

This literature review provides an overview of Indigenous STEM education that focuses on two key aspects: (i) the ways in which STEM education is incorporated within Indigenous teaching and learning contexts, and (ii) the frameworks, pedagogies and considerations through which emerging digital technologies are effectively applied to Indigenous STEM teaching and learning. Beginning with historical vignettes of Indigenous scientific practices to set the premise of our report, this narrative literature review traces developments and presents findings on the practice and progress of Indigenous STEM education in Australia.

The global scientific community is increasingly recognising the value of Indigenous knowledge in a range of critical focus areas today, that rely on STEM education, for example, environmental science, astronomy and ecology. Yet there is much work to be done if education policy-makers are to effectively 'close the gaps' between Indigenous and non-Indigenous educational attainment, engagement and post-school outcomes. We refer to a range of measures and interventions in this area such as the Closing the Gap report (2020), NAPLAN results, Program for International Student Assessment (PISA) report and other independent assessments which demonstrate that despite improvements, Indigenous students continue to perform below national standards for literacy and numeracy, and have lower school retention and completion rates than non-Indigenous students. These disparities are the result of deficits that have long existed in terms of education policy and learning design. Whether applying Indigenous pedagogy or teaching Western education to Indigenous students, educators have frequently noted limitations around curriculum design, professional learning, resource allocation and teachers' own perceptions in approaching Indigenous knowledge in meaningful, authentic and culturally responsive ways.

Intended as both a review of academic literature and a resource for educators, we begin our analysis of scholarship with noting differences and similarities between Indigenous and Western STEM education. After demonstrating the various ways in which Indigenous STEM knowledge and practice systems have existed over millennia, we note that like Western STEM, the scientific traditions of Indigenous Australians have relied on data collection, observation, prediction, hypothesis testing, and making generalisations to draw conclusions. As such, a vast array of literature suggests that Indigenous and Western STEM are often complementary to each other, despite their epistemic differences. Throughout this review, there are examples of how Indigenous Australian knowledge is being used by scientists and engineers trained in the Western academy. We highlight key policy developments that have resulted in strategies for the revitalisation of Indigenous STEM education, and our aim to discuss this 'revitalisation' in our review is to open a space for educators, students, and other stakeholders to understand STEM in diverse cross-curricula terms.

To this end, we present an overview of key pedagogical frameworks that have been utilised in the teaching and learning practices of Indigenous STEM. These include (i) embedding students' cultural identities and perspectives, (ii) using non-verbal, narrative-based, and reflective learning (8Ways), (iii) 'Two-Ways' or 'Both-ways' learning, or dual epistemologies, and (iv) 'On-Country' or place-based learning. Empirical examples for each of these pedagogic frameworks have been provided in this report, focusing specifically on their application for STEM education. However, developing pedagogies and teaching frameworks alone are not sufficient for a holistic response to an Indigenous STEM education agenda. We therefore, highlight a range of factors for educators at different levels that need to be considered in developing and incorporating Indigenous STEM initiatives. These include careful considerations around culturally responsive pedagogy, use of appropriate assessment, views on Indigenous student expectations, educator training and resources, and links beyond the classroom with industry and community.

This report has been prepared by the stem.T4L research team. Since 2018, stem.T4L has been providing NSW public schools and teachers with the opportunity to integrate innovative educational technologies into their classrooms – specifically, augmented and virtual reality, robotics, 3D printing and filming technologies. We therefore, review empirical studies on how some of these

technologies are currently being employed in Indigenous education contexts both in Australia and globally. Examples include wide-ranging school and community-based projects from land rehabilitation to 'Country-mapping' exercises.

Most researchers have demonstrated that teaching and integrating STEM in cross-disciplinary education has resulted in profound outcomes for Indigenous students and communities along with their non-Indigenous peers. Instances of increased student engagement and participation, improved school attendance, and interest in STEM are some of the key findings of the growing body of research in this field. Apart from Indigenous and non-Indigenous educators, this report will likely be useful for education policy makers, Indigenous community members and Elders, and other practitioners in the Australian education industry based on the multitude of themes and topics it engages with on policy, pedagogy, considerations, and Indigenous STEM initiatives.

INTRODUCTION

On a bend of the Barwon River, on Ngemba Wayilwan Country in north-western New South Wales, lies Baiame's *Ngunnhu*, the fisheries of creator God Baiame[1]. Also known as the Brewarrina fish traps, Baiame's *Ngunnhu* are a system of carefully arranged stone walls and weirs that were designed to herd fish across a half-kilometre stretch of river. A form of 'design thinking' that re-engineered the local waterway without disrupting it, the traps used the flows of the Barwon in such a way that many fish were efficiently harvested in hand-built ponds, others were 'stored' behind barriers for later consumption, and other fish were permitted to migrate upstream, spawn offspring and perpetuate the local ecosystem (Swag Family, 2019[2]). The traps helped sustain a large population and economy that was comprised of numerous local clans – approximately 5,000 people would attend the annual harvest (Pascoe, 2018). The Brewarrina fish traps were a gathering and sharing place that endured for millennia. They are a site of cultural and spiritual significance for the Ngemba, Ualarai, Murrawarri, Gamilaroi, Baranbinja, Koama, Wayilwan, Kula and Baarkkinji Peoples – communities that were evidently adept at innovating in order to survive and thrive in outback Country (Brewarrina Aboriginal Corporation, 2019). Both local oral history and formal land conservation studies have suggested that the Brewarrina fish traps are some of the oldest hand-built structures on Earth (Dargin et al., 1994). The local custodians of Baiame's *Ngunnhu* can be counted among the earliest scientists and engineers in the world alongside several others.

This account of Indigenous knowledge and history sets the premise of our review that traces discourses and developments, and presents findings on Indigenous STEM education in Australia. On the back of every Australian $50 note is the visage of David Unaipon, an Aboriginal scientist, preacher, author, and activist that most Australians have likely never heard of (Trimmer et al., 2017). In his career, Unaipon developed a patent for a sheep-shearing device that is still used today and, prior to the invention of the helicopter, he used the physics of the boomerang to sketch-up designs for a flying machine that could take-off vertically (Alexander, 2009). He was first person to have written about Aboriginal knowledge[3] and to have described it as a science in its own right. Despite being "the star pupil of a paternalistic mission culture", Unaipon's career was beset by many challenges – not least of all the fact that his writings on Aboriginal culture and his sheep shearing patent were claimed by others without him receiving compensation before his death in 1967 (Alexander 1997, p. 27-28).

These disparities have started to come to the fore as the global scientific community is increasingly recognising the value of Indigenous knowledge in a range of critical focus areas today, that rely on STEM education, for example, environmental science, astronomy and ecology. We use the term 'Indigenous STEM' in a broad sense. On the one

[1] *Pronounced 'By-ah-mee's noon-oo' (NSW Office of Environment and Heritage n.d.).*

[2] *The Swag Family is a primary school adventure learning project that explores the stories from the people and environment of Australia. More information is available on https://www.swagfamily.com.au/*

[3] *The terms "Aboriginal" and "Indigenous" is used interchangeably throughout this paper. Referring to Jorgensen et al. (2013), these terms are used as a shorthand in order to focus on writing that will help with the consistency and clarity of the content. We are conscious that both these terms are reflective of a multitude of people, cultures, languages and histories. In using these terms our aim is not to take away from this diversity, but to focus on aspects that unite Indigenous people and make their narratives different to non-Indigenous people, particularly in the field of STEM education.*

hand, Indigenous STEM can refer to the projects and pedagogies that attempt to make formal or 'mainstream' STEM education and employment more accessible that it has been for people like David Unaipon. Such projects seek to support the next generation of Indigenous scientists and entrepreneurs, and reduce the hurdles that they may encounter on their pathways through and beyond the K-12 classroom (Trimmer et al., 2017). On the other hand, Indigenous STEM education is an emerging field of pedagogy and curriculum in which both Indigenous *and* non-Indigenous students are provided with opportunities to understand and appreciate the STEM knowledges and traditions of Indigenous cultures, as evidenced in places like the Brewarrina fish traps. From fire management, medicine and astronomy through to ecology, land cultivation and much more, a wealth of Indigenous STEM knowledge and practice has been transferred across generations, which the education systems of contemporary Australia are only beginning to explore.

At present, there is both momentum and inertia within Indigenous STEM education. Many resources and commentaries have emerged in educational, academic and popular culture settings that seek to address the historical imbalance between the status of Western and Indigenous Australian STEM (e.g. ACARA, 2016; Deslandes et al., 2019; Pascoe, 2018). The potential is clear, particularly where the two dimensions of Indigenous STEM overlap. The 'Two-Way Science' movement, for example, teaches Indigenous scientific knowledge alongside 'traditional' STEM learning, and seeks to make science more culturally relevant for Indigenous students while also encouraging their uptake of 'mainstream' STEM education and careers (Deslandes et al., 2019).

Yet there is much work to be done if education policy-makers are to 'close the gaps' between Indigenous and non-Indigenous educational attainment, engagement and post-school outcomes. For example, data from the latest PISA report describes lower Indigenous Australian students' performance and proficiency scores in scientific literacy when compared with non-Indigenous students (Thomson et al., 2019). At the same time, however, we follow the copious educational researchers who have emphasised the need to move past 'deficit' understandings of Indigenous students or Indigenous science (Chaffey et al., 2015; O'Connor & Norton, 2020; Yunkaporta & McGinty, 2009). PISA or NAPLAN results need to be considered in light of the deficits that have long existed in terms of education policy or learning design. Whether teaching with Indigenous science or teaching Western science to Indigenous students, educators have frequently pointed to barriers in the form of: 'one-sided' curriculum design, a dearth of relevant professional learning (PL) for educators, limited resources (including time for teachers' PL) and teachers' own apprehensions about approaching Indigenous knowledge in meaningful, authentic, and culturally sensitive and responsive ways (Baynes & Austin, 2012; Burgess & Cavanagh, 2015; Burridge et al., 2012; Lowe & Yunkaporta, 2013; Michie, 2002).

The report is intended to provide both a review of academic literature and policy work in this field, while also being a resource guide for NSW educators. We begin with an introduction to Indigenous knowledge systems, the points of similarity and difference between Western scientific education and those of Australia's First Nations traditions. After tracing the policy developments of Indigenous STEM education, the report explores core pedagogical frameworks, themes and concepts emergent in Indigenous STEM teaching and learning in the K-12 classroom (Aikenhead, 2001; Deslandes et al., 2019; Irving & Hoffman, 2014). We then offer key considerations around issues of cultural responsiveness, appropriate assessment, use of language, personalised learning, expectations and educator professional development – as aspects that are critical for the practical and effective implementation and evaluation of Indigenous STEM. Empirical studies presented in the final section provide examples of how Indigenous STEM is being taught in schools with the use of digital technologies. A resource guide including material developed in some of these projects along with key reports and international case studies has also been created and can be accessed here. The conclusion highlights critical junctures from this review to reflect upon ways in which Indigenous STEM practices and applications contribute to the field of STEM education itself, and proposes considerations for future research.

METHOD

This paper conducts a narrative literature review that explores recent developments in Indigenous STEM education and the use of new digital technologies including coding and robotics, digital content production, augmented and virtual reality (AR/VR), and 3D printing. While narrative literature reviews are generally held to be less thorough than systematic literature reviews, it was deemed as more contextually appropriate for this work, as we report on several innovative education practices that are occurring at a highly localised level. The report also draws upon informal consultations with some Department of Education staff and educators within the NSW Aboriginal Education Consultative Group (AECG) and the Commonwealth Scientific and Industrial Research Organisation (CSIRO). These practices and viewpoints offer valuable insights for this review and would have been overlooked in conducting a formal systematic review of academic papers alone.

Academic literature was collated from numerous databases of peer-reviewed material using Google Scholar as a central search engine. Common search terms included 'Indigenous AND Aboriginal STEM education', however a series of selection criteria were deployed to narrow the number of consulted papers. The papers synthesised herein generally focus on Australian educational jurisdictions (both at a Commonwealth and state or territory level). However, a number of studies involving North American First Nations and New Zealand Māori students are included for their contextual relevance.

Non-peer reviewed material was collated through web searches and following consultations with policy and teaching staff within the NSW Department of Education (DoE), such as case studies or publications from peak bodies (e.g. Australian Curriculum Assessment and Reporting Authority [ACARA] and CSIRO). This has included non-academic sources, such as popular literature or other forms of public communication (e.g. magazine and news articles). While the report emphasises those studies and reports that have passed peer review, the emerging nature of Indigenous STEM education necessitates casting the net a bit wider. As noted earlier, a vast amount of innovative education practices and activities in Indigenous communities are occurring at highly localised levels and oftentimes, in informal educational settings. Specific examples of STEM applications in Indigenous communities are provided in the later sections of this review.

BACKGROUND: AN OVERVIEW OF INDIGENOUS STEM KNOWLEDGES AND PRACTICES

In this section, we present a broad overview of Indigenous STEM knowledges[4] and practices – from the scientific traditions emerging in the deep histories of Aboriginal and Torres Strait Islander cultures, through to these traditions' more recent acknowledgement in the educational policies of Australian jurisdictions and statutory bodies. Indigenous knowledge systems encompass science, technology, engineering and mathematics, all of which are predicated on a rich and empirical understanding of the natural world. This knowledge is embedded in holistic and complex inter-relationships between people, Country and the Dreaming, and is transmitted across generations through community norms and diverse forms of communication. We will thus explore the differences and similarities between Indigenous Australian STEM and Western STEM – the latter term referring to the Anglo-European knowledge systems that occupy the mainstream of contemporary K-12 STEM education. Following this discussion, we briefly explore Indigenous STEM within the broader trajectory of Indigenous education policy, which culminates in numerous imperatives to improve STEM educational outcomes for Indigenous students and the understanding and appreciation of Indigenous knowledge systems.

[4] *The reader will note the use of the plural 'knowledges' in this paper. The great breadth and diversity in Indigenous nations and language groups is reflected in diverse and localised STEM knowledges and practices across Australia and the Torres Strait Islands – of which we present only a brief account here. Where appropriate, we refer to the knowledges and practices of specific nations or language groups.*

Indigenous STEM knowledge and practice systems: 60 millennia and counting

Indigenous knowledge posits that Australia has been occupied since the beginning of the Dreamings. In Western scientific terms, archaeological evidence has confirmed that the Australian continent was inhabited by people at least 65,000 years ago (Clarkson et al., 2017). In either metric, Indigenous Australian cultures are the oldest living cultures on Earth (AECG, 2018). Australia's First Peoples survived in Australia over this period through a detailed and practical understanding of the natural world and its processes. Langton (2019) describes Indigenous Australians as the continent's first innovators, who have endured and managed wholescale changes in climate (such as an ice age), environment (such as sea level rise) and ecology (such as the death of the megafauna). Indigenous Australians cultivated a rich and diverse corpus of scientific knowledges and practices over 60 millennia.

Several scholars have noted how the dominant narratives surrounding Indigenous knowledges have often derided them as being 'primitive' or simplistic in comparison with Western STEM (Baynes & Austin, 2012; Matthews, 2019; Trimmer et al., 2017). It is also less common to see Indigenous Australian cultures appreciated in terms of their material practices and empirical knowledges – there is perhaps an emphasis instead on the spiritual and ceremonial dimensions of Indigenous cultures, removed from the day-to-day processes of living on the Land. These STEM knowledges have always had immediate practical applications: for example, Torres Strait Islander cultures used astronomical knowledge for weather forecasting and resource management (Hamacher, 2014). Appreciating Indigenous STEM in this way involves moving "beyond just a tokenistic 'spaghetti and polka' or 'bush tucker and corroboree' version of culture" (Michie, 2002, p. 37), and into deeper conceptual understandings of "Aboriginal ways of doing and thinking" (Lowe & Yunkaporta, 2013, p. 4).

The STEM knowledges and practices of Indigenous Australian history are being rediscovered and revitalised – in academic research, popular culture and in real-world practice. Aboriginal pyrotechnics is a fascinating example. Fire-stick farming represented the "long-perfected 'ecological engineering'" of Australian forests and grasslands: it cultivated an abundance of plant and animal species, made foraging and hunting more efficient and sustainable, and fertilised the soil by releasing carbon and nitrogen during burns (Walker, 2013, p. 392-3). Given Australia's recent experiences of fire, "where fuel builds up and results in wild infernos in the late dry season" (Walker, 2013, p. 392), it is not surprising to see renewed interest in Indigenous pyrotechnical knowledges for contemporary bushfire mitigation and in carbon abatement projects (Ansell et al., 2020).

Indigenous STEM knowledges should be appreciated in their own right, independent of the knowledge systems of the Western world. For those of us trained and educated in the latter, however, explaining central concepts in Indigenous STEM with reference to Western knowledge can be helpful (a method of comparison which informs the Australian Curriculum). Readers of the literature on Indigenous STEM education will invariably encounter two particular terms: epistemology and ontology. Derived from the Greek word episteme – translating as 'knowledge' or 'understanding' (Steup & Neta, 2005) – epistemology is the study of knowledge itself. Epistemological questions investigate our ways of knowing: how do we know what we know, and what are the sources of our knowledge? Ontology, meanwhile, is derived from *onto* or 'being' – ontological questions ask us to consider what *is* or what *exists*. 'Is there a God?' is perhaps the most recognisable ontological question human beings have asked, though the ontological branch of philosophy is also concerned with "general features and relations of the entities" that exist in the world (Hofweber, 2017, para. 7).

Broadly speaking, Western STEM rests upon the ontological and epistemological 'first principles' that we exist in a rational and secular universe, in which the natural world can be understood through consistent 'laws' or explanations that are independent of our individual experiences. In contrast, Indigenous STEM has both material and spiritual characteristics: knowledge is derived from the ancestral beings of Dreaming and has been passed down by local knowledge holders to community members, and this knowledge is embedded and represented in local Country.[5] Indigenous knowledge systems are thus interwoven into complex and multifaceted relationships between Indigenous Peoples, the

[5] *Elders and other senior members of an Indigenous community are holders of knowledge of the natural world and related teachings of the Dreamings and, as Williams (2014) further explains, these ways of knowing were transmitted to younger people when appropriate to either whole of community knowing, female or male knowing and the "pre-determined spiritual custodianships" of an individual or group (Williams, 2014, p. 3). From student to teacher to graduate researcher to Professor, Western STEM of course has its own social hierarchies that are evident in the transmission of knowledge.*

Dreaming and Country. Understanding these philosophical points of distinction is important in practical terms because, as numerous researchers have noted, efforts to improve STEM educational outcomes for Indigenous students are often hampered by "mismatches" between the epistemological and ontological characteristics of Indigenous and Western knowledge (Osborne et al., 2016, p. 51).

While Western STEM presents itself as objective and value-neutral, in Indigenous knowledge systems there are inextricable social, spiritual, political and moral dimensions associated with scientific knowledge and practice. The fish traps at Brewarrina, for example, were refined and improved over centuries through the practical knowledge of the local Peoples, and this knowledge is also understood and communicated through teachings from the Dreaming. Furthermore, while Western understandings of the natural world are often compartmentalised into discrete disciplinary boundaries – from broad categories of the 'natural sciences' or 'the humanities' to specialisations like biology, physics, visual art or law – Indigenous knowledge systems are much more holistic in character and in practice. Teachings from the Dreaming, understandings of local geography and concepts in Aboriginal astronomy thus entwine to become – in the words of local knowledge holders – "a sky atlas, and a big library that defines things" (Fuller et al., 2013, p.8).

Rather than being disembodied or abstract, Indigenous STEM knowledge is both fundamentally place-based and transmitted through mediums that are more tangible than the more antiquated pedagogies of the Western STEM classroom. All knowledge derives from Country and Indigenous Peoples' intractable sense of belonging to Country, and this knowledge "was packaged, stored and transmitted within the mediums of story, song, music, dance and art" (Williams, 2014, p. 3). For example, "[art] often encodes the geography of a landscape" (Deslandes et al., 2019, p. 15), while the observed behaviours of local animals are often encoded in dance and music. These mediums encompassed visual, narrative and participatory forms of teaching and learning, and were "communicated in ceremonial and non-ceremonial forums" and used "both verbal and non-verbal vernaculars" (Williams, 2014, p. 3).

Again, these features of Indigenous knowledge systems are fundamentally practical. To use one final example from Aboriginal astronomy, celestial navigation enabled First Nations explorers and diplomats to safely traverse the vast distances of the Australian continent. In Euahlayi knowledge, stars were used as a memory aid to teach people to navigate on long journeys from (what is now) Goodooga to destinations up to 1,500 km away. The journey itself was taught as a songline, a story that travels over and is imprinted with the landscape (Mackay et al., 2016). Certain stars represented the waypoints of these routes across Australia, a mnemonic that helped the Euahlayi find waterholes and shelter on their way to meet people from other nations for ceremonies, gatherings and trade. It is but one example of Indigenous STEM education as it has existed for over 60 millennia: learning on Country, through pedagogies of sky, soil, water and song.

The scientific method: similarities between Indigenous and Western science

Turning to points of similarity between Indigenous and Western STEM invariably raises some philosophical questions – what is science? What do we understand to be the 'scientific method'? These questions lie at the heart of contemporary K-12 engagements with Indigenous STEM. As Baynes and Austin (2012) found, at least some members of the teaching community have dismissed Indigenous STEM as being not 'scientific' – or, at least, not commensurate with their own understanding of what science is and can be.

As discussed above, Indigenous STEM has "ontological validity that is independent of the 'hard' sciences" of Western STEM (Lowe & Yunkaporta, 2013, p. 8). In terms of content knowledge, however, there are numerous parallels and synergies that can be identified with the disciplines of Western STEM – such as astronomy, ecology, geology, hydrology, meteorology, medicine, pyrotechnics, and more. This is also true in terms of how knowledge is organised in the two sciences. For example, Indigenous Australian knowledges also involve systems of number and taxonomic or binary categorisations of the different relationships that exist within and between people and nature (Matthews, 2020).

Like Western science, Indigenous STEM has a strong empirical basis. Indigenous knowledge systems rely upon the collection of sensory data – the process of understanding the world through observation. While the over-arching worldview is different, Indigenous STEM similarly involves the collection of data from the observable physical conditions of the natural landscape. The seasonal calendar, for instance, breaks the annual cycle down into six seasons, with each being demarcated by changes in particular biotic and abiotic variables – like changes in weather, vegetation and animal behaviour. The D'harawal calendar, for example, collates data around the time of Wiritjiribin (the lyrebird). Mating calls of the lyrebird and the flowering of the Marrai'uo plant indicate an increase in cold and windy weather (Tugarah Gunya'marri, in approximately August). When lyrebird males have built their mounds, the season ends and warmer weather is known to be approaching (Bodkin/Andrews clan of the D'harawal People[6]). This observational data might be recorded and encoded in song, story, art or dance – as opposed to the conventions like laboratory notes, peer-reviewed papers and conference presentations – but the scientific methods of Indigenous Australians are similarly empirical.

In addition to the collection of data, there are numerous scientific practices with evident parallels between Indigenous STEM traditions and those that dominate mainstream K-12 syllabuses. As researchers with the CSIRO have acknowledged, the scientific traditions of Indigenous Australians have developed knowledge about the world through observation, using all the senses; through prediction and hypothesis; through testing (trial and error); and through making generalisations within specific contexts[7]. For example, the Barkindji Peoples of far west NSW stored live freshwater mussels in 'larders' one metre underground (ACARA, 2019). The knowledge that mussels can survive for months in moist sand, away from riverbeds, was clearly the result of observation, hypothesis and testing – as was the application of this knowledge through resource management in harsh outback climate.

Parallels with Indigenous ways of thinking and knowing are also evident in the seemingly discordant domains of digital technologies and the computer sciences. The CSIRO's Indigenous STEM Education outreach team have outlined the ways in which the core computational thinking skills – decomposition, pattern recognition, abstraction and algorithm – have precedents in Indigenous ways of knowing (Tynan & Noon, 2017). The multilayered storytelling of the Dreaming involves forms of *decomposition*, in which a complex narrative or 'problem' is broken down into its component parts. Pattern recognition, as a practice in Indigenous knowledge, can be seen in the seasonal calendar or in tracking human and animal footprints. Indicators of seasonal change or imprints in the soil are recurring data points that can be extrapolated from when explaining wider phenomena or when completing certain tasks. Non-verbal communication – such as through visual representations in art or the symbolic representations of language in 'sand talk' (Yunkaporta, 2019) is a form of *abstraction*, in which a model is constructed from relevant information and less relevant information is filtered out. Finally, Indigenous Peoples have been using the step-by-step logic that is central to writing *algorithms* for millennia, whether by weaving plant fronds into water purifying devices, stitching possum hides into winter cloaks or by following the star waypoints in a songline across inland Country.

For these reasons, Indigenous and Western STEM are often complementary to each other, despite the differences in their worldviews and epistemologies. There are numerous examples of where Indigenous Australian knowledge is being used by scientists and engineers trained in the Western academy, in addition to the above example of Aboriginal fire-stick farming. There is evident commercial potential for the revitalisation of the Indigenous sciences and, so long as proper recognition and compensation is given to Indigenous communities, for the development of new projects in Indigenous entrepreneurship.

Our aim in discussing the 'revitalisation' of Indigenous STEM knowledge is to open a space for educators, students and stakeholders to understand STEM in cross-curricula terms. Indeed, it is essential that we understand Western STEM as being implicated in the violent exercise of British colonialism. The death, displacement and subjugation of Indigenous Australians was, in large part, an exercise of imbalances in scientific and technological power. As

[6] *Weather cycles around Sydney from the Bodkin/Andrews clan of the D'harawal People:* https://www.abc.net.au/science/features/indigenous/calendar2.htm

[7] *As outlined in The Aboriginal and Torres Strait Islander Histories and Cultures (Version 8.4):* https://www.australiancurriculum.edu.au/f-10-curriculum/cross-curriculum-priorities/aboriginal-and-torres-strait-islander-histories-and-cultures/

Pascoe (2014) has argued to great effect, discrediting the achievements of Indigenous Australian STEM fed directly into the myth of *terra nullius* and the misconception that Indigenous Australians were 'hunter-gatherers' without very clear and evident practices of settling, cultivating and engineering the land. To borrow the terminology of the Australian Curriculum's general capabilities, "science as a human endeavour"[8] has benefits that have been distributed unequally over the course of human history. As we will explore in this report, many educational researchers have found that there are very clear pedagogical, affective and measurable benefits in understanding how intersections between Indigenous STEM and Western STEM have social, cultural, political, economic and colonial underpinnings that have evolved over time (Aikenhead, 2001; Baynes, 2015; Matthews, 2019; Yunkaporta & Lowe, 2013).

Policy change in Indigenous education: teaching and learning with Indigenous STEM in K-12 classrooms

Indigenous ways of teaching and learning were severely disrupted from 1788 onwards and were effectively displaced by Western models of education. It is only in the early years of the 21st century when educating *all* students in the knowledges and practices of Indigenous Australian cultures is mentioned in state or federal education policy. While we present only the major milestones on this journey, it is worth considering that practical reconciliation is gradually being realised in mainstream education policy.

Burridge and Chodkiewicz (2012) describe three waves of early Indigenous education, between the arrival of the First Fleet up to the passing of the 1967 referendum relating to Indigenous Australians. First, a period from 1814 to the 1880's, in which one 'Native Institution' was established in Blacktown for the segregated education of Indigenous students, but education was provided predominantly through the mission schools of church and charitable organisations (a setting in which David Unaipon was educated). Second, a period from the 1880s to 1930s, when the *Public Instruction Act 1880* prompted a brief expansion of access to education for all students in NSW, at least in principle. However, the establishment of the Aboriginal Protection Board in 1883 pushed more Indigenous students into Aboriginal-only schools, often through the forced removal of 'neglected' students. Students outside of missions tended to suffer from "being expelled, excluded or prevented from attending school" (Burridge & Chodkiewicz, 2012, p. 15). And third, policy decisions from the Commonwealth and NSW governments' in the late 1930s pushed Aboriginal education into an assimilationist period that lasted for nearly 40 years. Little formal recognition was given to Indigenous knowledges and there was tangible policy intervention that sought to improve educational outcomes for Indigenous people was sparse (Burridge & Chodkiewicz, 2012).

In the past half-century, however, progress has gathered pace in improving Indigenous Australians' access to education and appreciating and understanding Indigenous knowledge systems in the classroom. In 1967, the year of David Unaipon's death, Aboriginal and Torres Strait Islanders were formally counted as part of the Australian population, following a referendum that also allowed the Commonwealth to make laws concerning Indigenous Australians in state jurisdictions (including education). By 1975, the work of Aboriginal educational advocates lead to the establishment of an Aboriginal Consultative Group in the Commonwealth Schools Commission which, in turn, provided states and territories with funding to establish state-level consultative and advisory groups – like the NSW Aboriginal Education Consultative Group (AECG, est. 1977). In 1982, the NSW AECG worked in close partnership with the NSW Government in drafting the state's first Aboriginal Education Policy (AEP).

In the period between the 1990s and 2010s, an increasing effort has been made to improve educational outcomes for Indigenous students, alongside a gradual expansion in the number of teaching programs that incorporate Indigenous STEM knowledges and practices. At a state level, the NSW DoE and Board of Studies ran projects at the turn of the millennia – such as the Counting On programme (2001-2) and the *Mathematics in Indigenous Contexts* projects (2002-3), respectively – that focused on culturally relevant mathematics

[8] *As mentioned in "The three interrelated strands of science":* https://www.australiancurriculum.edu.au/f-10-curriculum/science/structure/

teaching for Indigenous students in low-income areas (Matthews et al., 2003). More recent examples are discussed in the following sections for this report.

At the national level, the Coalition of Australian Governments (COAG) set ambitious targets for Indigenous education in the 2008-2009 *National Indigenous Reform Agreement* (COAG, 2009). Progress on meeting these targets is communicated annually through the *Closing the Gap* reports. In 2015, ACARA's Australian Curriculum was endorsed by state and territory Governments. This included a series of *Aboriginal and Torres Strait Islander Cross-curriculum Priorities* that, while they "do not constitute curriculum on their own", are presented to teachers and students through content elaborations that provide "depth and richness" across key learning areas (ACARA, n.d.). In 2019, ACARA published an extensive guide to exploring the content elaborations for these *Cross-curriculum Priorities* in K-10 science classes (ACARA, 2019).

However, the NSW AECG have noted that while some progress has been made in select *Closing the Gap* targets, there is still widespread disparity between Indigenous and non-Indigenous students in terms of school attendance, Year 12 attainment, and enrolment and completion rates in university education (AECG, 2018). When comparing Indigenous and non-Indigenous students using Trends in International Mathematics and Science Study (TIMSS) metrics, the "gap has changed little over 20 years" (Department of Education, Skills and Employment [DESE], p. 23). The Australian Curriculum's engagement with Indigenous ways of knowing and thinking have also been criticised. *Cross Curriculum Priorities* tend to focus on "simple factual content" rather than the systematic, holistic and socio-political features of Indigenous ways of thinking and doing (Lowe & Yunkaporta, 2013, p. 4). Moreover, the curriculum's preference for lower order verbs like 'consider' and 'investigate' – as opposed to 'evaluate' or 'critique' – embeds "low-level cognitive expectations on student learning" (Lowe & Yunkaporta, 2013, p. 6). Bearing these criticisms in mind, in the sections that follow we will explore new and successful means of improving educational outcomes for Indigenous students. Moreover, we explore how culturally-relevant pedagogies and exciting new technologies can combine to improve the understanding and utilisation of Indigenous STEM for *all* students.

PEDAGOGIES IN CONTEMPORARY INDIGENOUS STEM EDUCATION

This section explores the core pedagogical features in contemporary Indigenous STEM education beginning with the ways in which students' cultural identities and perspectives can be embedded into Indigenous STEM pedagogy. We then explore the concepts and applications of non-verbal, narrative based and reflective learning, followed by explorations of 'Two-Way' learning and 'On-Country' or place-based learning frameworks. There is much overlap between these categorisations. For example, a Two-Way science program will likely involve On-Country learning and diverse methods of instruction. Owing to the recent proliferation of interest in Indigenous STEM, there is a relative paucity of evaluation data relating to these pedagogies. Nonetheless, we point to programs that have demonstrated success in teaching with these pedagogies.

Embedding students' cultural identities and perspectives

To privilege Western models of STEM education – and the understandings and practices of the Anglo-European scientific tradition embedded within Western STEM – is to privilege Western culture. It is of course true that an education in Western traditions gives both Indigenous and non-Indigenous people economic independence (AECG, 2018). This is the reality of a global job market in which most opportunities for employment and career progression rest upon a mainstream of Western ways of knowing. However, as Aikenhead noted in his extensive research into STEM education with Aboriginal Canadian students, "The world in which most Aboriginal students participate is not a world of Western science, but another world increasingly influenced by Western science and technology" (Aikenhead, 2001, p. 339). Teaching Indigenous students about Western STEM using approaches that do not recognise, respect, embed and reflect upon their own unique and diverse cultural identities is a pedagogy that devalues Indigenous traditions (Guy, 2016; Matthews et al., 2007). Such an approach can alienate Indigenous students from STEM education

at the very outset. The Aboriginal Summer School for Excellence in Technology and Science (ASSETS) program by CSIRO has aptly recognised that embedding cultural identity in STEM education generates interest and confidence in STEM through (i) increasing awareness around the ongoing contributions of Aboriginal and Torres Strait Islander Peoples in STEM; and (ii) leveraging the role of cultural identity as a source of strength and resilience in navigating pathways and progressions in STEM fields. Researchers found that students who had closer associations with their culture and heritage found it easier to make connections between Indigenous knowledge and current learning approaches.

Incorporating cultural Identity in STEM disciplines

Following on from these understandings, several Australian researchers have explored the significance of cultural identity in STEM education across multiple disciplinary fields. For instance, The Aboriginal and Torres Strait Islander Mathematics Alliance (ATISMA) introduced the *Goompi Model* of maths education that allows students to use storytelling to understand mathematical expressions and build understandings of arithmetic symbolism (Australian Education Union [AEU], 2019). Professor Chris Matthews who chairs ATISMA and created the Goompi Model, posits that students can generate their own expressions of mathematics by drawing upon inferences from their own world and identity. As an example, he explained that linear equations may be understood through naturally occurring patterns such as the phases of the Moon or changes in colours of a lizard (C. Matthews, personal communication, November 25, 2020).

Another example is the Yirrkala School in North East Arnhem Land that is teaching mathematics to students by highlighting the systems thinking that is already embedded in *Gurruṯu* - the "interconnected relationships between *all the elements of the world*, such as those between people, animals, plants, insects, wind, fire, water, land and so on" (Matthews, 2020, para. 5). The school has also adopted a wider cultural curriculum called *Galtha Rom*, or cultural lessons that emphasises on a 'Both-ways' bilingual approach to education where education is provided in a child's first language alongside English (Masters, 2021). The need to incorporate Indigenous culture and perspectives has also been explored in other STEM disciplines such as astronomy, chemistry and physics. For example, ACARA elaborations, mentioned in preceding sections, are developed for teachers to incorporate indigenous histories and cultures in a range of cross-curriculum priority areas. Students can, for instance, learn chemical reactions by exploring methods employed by Aboriginal and Torres Strait Islander Peoples to convert toxic plants into edible foods, or learn about the physical conditions of their environment by investigating indigenous understandings of conditions necessary for certain plants and animals to survive (ACARA, 2018).

8 Ways of learning: non-verbal, narrative-based and reflective learning

Indigenous holistic pedagogies are based on facilitating students' interpersonal communication and collaboration through ways of learning that emphasise on 'community' (Yunkaporta, 2010). In contrast, Western education focuses on students' 'individualised' capabilities of critical, creative and analytical thinking and problem solving. As such, individuals themselves form or build communities, as they are ontologically independent (Dreamson et al., 2017). Aboriginal holistic pedagogies are developed to be 'relationally responsive' based on perspectives and ways of thinking rather than methods or content that is to be taught or delivered. This requires a shift away from tokenistic applications of Indigenous educational content that is often separated from the core syllabus and treated as an 'interesting' or 'fun' activity.

Recognising these issues and pedagogical differences between Indigenous and Western education delivery, Yunkaporta (2009) developed "8Ways" (as nicknamed by teachers), as a pedagogical framework designed to include Aboriginal perspectives by using Aboriginal learning techniques. 8Ways initiated as a research project and continues to evolve through collaboration between NSW DoE staff, James Cook's school of Indigenous Studies and Western NSW Regional Aboriginal Education Team (RAET). Rather than focusing on "indigenised" content, the premise of 8Ways is to shine light on Aboriginal pedagogical perspectives through Indigenous processes of knowledge transmission. In its simplest form, the framework advances Indigenous perspectives of

learning through (i) story sharing (tell a story), (ii) community links (making a plan), (iii) deconstruct/reconstruct (think and do), (iv) non-linear (draw it), (v) land links (take it outside), (vi) symbols and images (try a new way), (vii) non-verbal (watch first, then do), and (viii) learning maps (share it with others). Community remains at the core, and learning is perpetuated by cultural exchange between diverse stakeholders including not just teachers, students, parents and community members but by broader, more spiritual interconnections between human, animal, and nature that are aligned with Aboriginal Dreaming.

Applications for STEM teaching and learning

The 8Ways pedagogical framework has vast and far-reaching applications, provided educators are able to identify Aboriginal systems in Country and culture as 'real ways' of learning and creating rather than as 'lost' or 'dying' cultural artefacts (8Ways, 2021). As Yunkaporta (2010) explains, this way of learning draws together research describing Aboriginal pedagogy as group-based, localised and connected to real-life applications and purposes. The 8Ways website reiterates this pedagogical understanding and shares a range of classroom contexts within which this framework has been explored and developed. One example with particular application for STEM included a cultural immersion training for teachers which was aimed at encouraging critical and creative uses of digital technologies among students applying the 8Ways framework (learning maps, story sharing, symbols and images and land links). Using Google Earth 5, participants created virtual narrated tours as an Aboriginal person spoke about their life and the relationship they had with their community and local sites. Participants were then broken down into groups and used the skills developed to create their own narrated tours. Teachers who participated in the cultural immersion training shared experiences of developing a stronger understanding of Aboriginal culture and history, while also learning a new technology.

8Ways also provides examples of a holistic cultural approach to mathematics, in describing that "rather than trying to bring out the culture in maths, we need to bring out the maths in culture" (8Ways Wiki). The website demonstrates, for example, exercises that involve examining communities and reflecting upon contemporary cultures and attitudes involving money, assigning values to objects, places and people, observing symbols and patterns in the environment, or drawing comparisons between things. Non-verbal hands-on learning is facilitated and supported by the use of visualisations, pictorial graphs, measuring, and drawing. Land links are established by working with natural phenomena such as trees and plants and observing geometrical references in the built environment (8Ways-maths). These examples further highlight cross-disciplinary and inter-disciplinary modes of learning as non-linear and experiential methods intermingle with concepts from science, mathematics, art and history.

Two-Way or Both-ways learning and dual epistemology

'Two-Way learning' has been evolving since the 1980s and is informed by the intersections of Indigenous standpoints and the White normative standpoints in education theory, which seek to equalise the claim between the validity of "White knowledge" and Indigenous knowledges that have historically been deemed as less scientific (Purdie et al., 2011; van Gelderen, 2017; Coff & Lampert, 2019). However, the approach has been applied in vastly different ways encompassing manifestations such as 'Indigenous Learning-Style', 'team-teaching' and full 'bilingual/biliteracy' methods and policies, and at worst, has become a summation of almost any bureaucratic attempt at 'cross-cultural consultation' in Indigenous communities (van Gelderen, 2019). Literature also points to the separation of 'Both-ways' education, where both Indigenous and non-Indigenous cultural and knowledge systems are integrated together in more holistic way (Nakata et al., 2012). Despite its variations, 'Two-Way' or 'Both-ways' at its core is an acknowledgement that mainstream educational goals need to be balanced with local Indigenous pedagogical systems. The Australian Council on Education Research (ACE) compiled numerous accounts of teaching and learning at this 'cultural interface' (Nakata, 2007), emphasising that a reflective, Two-Way approach can produce improvements in terms of metrics like school retention, literacy and numeracy, while also making teaching more relevant in terms of Indigenous students' self-concept and identity (Purdie et al., 2011).

Two-Way learning in STEM education

More recently, Two-Way approaches are being applied to STEM fields, known as either 'Two-Way Science' (Deslandes et al., 2019) or 'dual epistemology' approaches (Osborne et al., 2016). These pedagogies incorporate Indigenous ways of thinking, knowing and doing into teaching and learning practices of mainstream STEM classwork.

At a national level, the CSIRO's Indigenous STEM Education project has become a leader in this field with numerous programs that engage Indigenous students. Last year, the CSIRO published *Two-Way Science: An Integrated Learning Program for Aboriginal Desert Schools* (Deslandes et al., 2019). The authors describe a cycle of Two-Way science learning and teaching, with Indigenous ecological knowledge at its foundation: a planning phase connects traditional knowledge to the curriculum; core concepts (from both knowledge systems) are taught in class as preparation for learning on Country, which involves "Aboriginal experts [leading] the learning [and] Aboriginal Language...used wherever possible", yet Western scientific practices can occur alongside (Deslandes et al., 2019, p. 10). This is followed up with learning in class, where samples or evidence collected on Country can be integrated with activities like STEM investigations or art projects, and the cycle ends with students reflecting on their experiences within the class or school and with the wider community. Here, we also note the intermingling with On-Country learning, which, as a distinct pedagogical framework is discussed in more detail in the following section. CSIRO's Two-Way Science approach is applied to five topic fields – water; animals; plants; places; maps and Country; and seasons, weather and astronomy – for which the authors provide a number of suggested units and activities (Deslandes et al., 2019). STEM objectives from the project include but are not limited to outcomes such as survey mapping, data analysis and visualisation, science investigation and assessment, and multimedia editing.

On-Country and place-based learning

The idea of using outdoors as classrooms is not new and has been implemented in geographies across the world in the shape of 'forest schools' and organised outdoor programmes in Europe, China, Australia, North America, Canada, South Africa and New Zealand amongst others (Jackson-Barrett & Lee-Hammond, 2018). However, this organised approach largely neglects the notion of 'Country' as a space that is imbued with stories, songlines and knowledges that create worldviews and ways of being. In this context, learning outdoors has been used by Indigenous Elders for centuries as classrooms of Aboriginal teachings based on the explorations of the landscape and natural environment. This method of teaching has more recently come to be known as 'On-Country learning' or 'place-based pedagogy' wherein a learning environment that is deeply connected to culture, heritage, history and identity informs ways of learning (Gruenewald & Smith, 2008). The objective of On-Country or place-based learning pedagogies is to emphasise on experiences that encourage exploration, experimentation and collaboration with peers, teachers and community Elders. Moran et al. (2018) have further elaborated on On-Country learning as conceptually tied to deriving knowledge from the "intelligence of living environments" embedded in patterns emerging from the intersections of place and consciousness (p. 76).

Similar to Indigenous pedagogies discussed earlier, 'On-Country' or 'place-based' education has various iterations and ideologies. It is also important to note that On-Country pedagogies are not based on Country understandings from a remote or rural perspective that are somehow distant or disconnected knowledges that need to be brought to the fore. Rather, these pedagogies advocate for a 'place-conscious' education where 'situated knowledge' based on the "character and quality of places" features substantially in the "purpose, process and assessment" of teaching and learning (Grunewald, 2003, p. 645). Seminal work includes ideas from Freire (1970) who revolutionised education models by linking them to notions of place in Indigenous knowledge systems and methodologies. More recently, Arenas' (1999) 'pedagogy of place' offers a realignment of globalisation studies for

children to strengthen knowledges of their own place in order to comprehend those of distant places. From a remote learning context, Fogarty (2010) argued for a 'learning through Country' agenda that is based on a localised 'bottom up' approach and involves learning aspects of land, language and culture and ceremonial manifestations of heritage and identity, which can then be linked with mainstream curriculum. In a similar approach, The Australian Learning and Teaching Council (ALTC) funded an ICT-based program in which Yolŋu (the Aboriginal People of north-east Arnhem Land) and academic institutions partnered to engage in learning 'from Country' (van Gelderen & Guthadjaka, 2019). This pedagogical framework was described as distance learning in reverse, where educators from remote places delivered lectures and educational content to students based in metropolitan areas. These multiple iterations (amongst others) for On-Country or place-based pedagogies reflect a central objective that is attentive to the value of local Indigenous knowledges as authentic and critical - the kind of legitimacy often attributed to mainstream STEM education. The following section turns to a review of some empirical applications of On-Country pedagogies in the teaching and learning of STEM.

Using On-Country pedagogies to enhance STEM education

For over centuries, Australia's First Peoples have engaged in practices of land management, agriculture, biodiversity, food science, medicine, astronomy, ecological sustainability and environmental protection – issues that are highly relevant in contemporary STEM education. Environmental science is one key area due to its inherent connections to land and nature. In a recent study on rural students STEM outcomes, Morris et al. (2019) found that students' learning was greatly improved by place-based activities that involved a land rehabilitation project. Working collaboratively with researchers, scientists, teachers and community Elders on a real-life restoration project that involved understanding soil, native plants, minerals and Aboriginal Land cultures, had resulted in shaping positive views around science and learning science for students.

CSIRO's *Science Pathways* is another program based on On-Country projects within the context of STEM teaching and learning. The main objective of the program is to increase STEM engagement and achievement in schools, particularly within Aboriginal communities. Trialled in different Indigenous communities across the Northern Territory and Western Australia, it was identified through the program that students who were less engaged in the classroom were 'transformed' when they went 'out bush' (Tynan & Noon, 2017). Across the breadth of the program, the On-Country approach resulted in STEM learning outcomes through science activities that involved Western science and Traditional Ecological Knowledge (TEK). One successful example of *Science Pathways* included a fish monitoring project that involved studying about fish anatomy and habitats in Warralong using digital data collection and analysis tools. The project's localised approach dramatically increased students' school attendance as it captured their interest in native fauna and ecosystems. Another example involved a class project that conducted research and investigation on wedge-tailed eagles through radio-tagging alongside referring to relevant websites and digital resources, thereby allowing students to gain appreciations of local wildlife, landscapes and biodiversity through different types of digital technologies (Tynan & Noon, 2017).

Researchers have noted that the physical and social aspects of the environment, imbued in practices of place-based learning can further be enhanced and augmented by the use of emerging technologies. Educational apps like *Indigenous Learning App* and *Melbourne Dreaming* draw upon references to significant places, local languages and Indigenous heritage and culture amongst wider Australian communities and schools. An array of scholarship has also explored the ways in which Indigenous understandings of place and Country can be technologically inferred and understood by multi-modal tools such as photovoice journaling (Bennett et al., 2019), visual communication design (St John & Edwards-Vandenhoek, 2021) and AR (Herodotou et al., 2019). A more in-depth analysis of different types of digital technologies and their applications for Indigenous STEM teaching and learning is detailed in the following sections of this report.

KEY CONSIDERATIONS FOR INDIGENOUS STEM EDUCATION

Extant empirical research has pointed to the concerns around how the Australian school curriculum has incorporated Indigenous knowledges and the ways in which these knowledges are brought to the classroom. Since Aboriginal knowledges continue to be applied as aspects of Western education systems, there are constant tensions and ethical dilemmas around what counts as legitimate knowledge in the development of programs that are inclusive of Indigenous content (Lowe & Galstaun, 2020). Within the research community as well, 'Indigenous science' is defined and interpreted differently by different researchers. Abrams et al. (2018) explain how from Eurocentric science perspectives that dominate Western STEM teaching and learning models, there are no clear distinctions between Indigenous knowledges and Indigenous science as both fields refer to "ways of living in nature" (p. 7). They state that this type of classification ignores the fact that in most Indigenous communities there may not be appropriate words that correspond to Western notions of knowledge and science. How then, can existing education systems incorporate legitimate and authentic integrations of Indigenous STEM in the curriculum for the purposes of both student engagement and pedagogic enhancement? To answer this, we offer some key considerations in the sections below.

Authentic engagement through a culturally responsive pedagogy

While the Australian Curriculum has examples of Indigenous content being tied to 'scientific' knowledge, questions still exist around the genuine respect and application for Indigenous knowledge, especially when learning outcomes need to align with normative understandings of science. As argued by Lowe and Galstaun (2020), the Australian STEM education landscape appears to be functioning in a "liminal space: unable to see how Aboriginal and Torres Strait Islander educational content can be 'authentically' linked to student learning within a curriculum that prioritises discipline specific knowledge" (p. 94). One perspective, consistent across diverse Indigenous pedagogical frameworks explored in the preceding sections of this paper, is the proactive development of culturally responsive content that infuses the curriculum with rich connections to students Indigenous cultural, linguistic and community backgrounds.

Lewthwaite et al. (2015) have developed a framework for culturally responsive pedagogy that focuses on teachers own examinations of their beliefs, values and understandings of Aboriginal people and culture prior to working with Indigenous students and cultural knowledge systems. This kind of self-assessment allows teachers to be better prepared for working with Indigenous students and content in the classrooms. In a similar sense, Lowe and Galstaun (2020) have argued for educators to critically investigate current curriculum and establish pedagogic narratives that contextualises Indigenous content meaningfully into existing education models. The key metric here is a shift away from a focus on standardised educational outcomes to a broader consciousness-raising exercise wherein both teachers and students develop critical ethical tools to effectively transform existing modes of hybrid learning. In another study, Munn et al. (2006) highlighted the effectiveness of teaching that is based on students' strengths through adopting a culturally responsive teaching methodology. When content and its delivery is made more culturally compatible, it can result in improved academic and mentally stimulating outcomes for students (Rahman, 2012). Such a focus involves, for instance, teachers providing students with ample opportunities to make meaning from their specific life-worlds in ways that genuinely respects Indigenous knowledge and replaces the requirement or assumption that it is only legitimate if it responds to what is considered as 'normative' scientific understandings (Lowe & Galstaun, 2020). Others such as Barry (2016) invite educators to focus on the characteristics of the Australian Indigenous experience such as the use of Aboriginal English, an awareness of the sense of independence and autonomy that Indigenous children are raised to embody, and the focus of Aboriginal culture on collective community outcomes rather than individual achievement.

Appropriate assessment

Since the commencement of NAPLAN in 2008, although results have shown some improvements in Aboriginal and Torres Strait Islander student outcomes, they are still well behind their non-Indigenous peers (Goss, 2018). A recent report by the Grattan Institute highlighted that these gaps are not just limited to remote and isolated outback communities but are also emergent in regional and metropolitan contexts. The Closing the Gap (2020) report further demonstrated that despite improvements, 17 to 19 per cent of Indigenous students were below national standards for numeracy. On average Indigenous students also have lower school retention and completion rates than non-Aboriginal students. On one hand, these gaps raise questions around the effectiveness of education systems to support the needs of Indigenous students. On the other hand, they pose challenges to prevailing student assessment models itself. In other words, are assessments equal and fair for all groups of students?

A number of perspectives have been put forward that need to be considered in understanding what entails equitable assessment for Indigenous students. These considerations also have bearings on the issues related to the content that is assessed. Consistent with the discussion in the previous section, research on Indigenous assessment practices emphasises the need for culturally responsive perspectives towards assessments. Using this framing, Klenowski (2009) has argued for a 'culture-fair' assessment model that needs to consider students' cultural subjectivities through an ongoing process that requires communication, negotiation and deliberation between multiple stakeholders within a schooling community. Murphy et al. (2008) provide further elaboration on the role of negotiation in designing assessments through a sociocultural perspective. They argue for a shift in viewing assessments as something that is given to students to something that is being constructed *with* students and *for* students. Personalised learning plans or pathways (PLPs) are one strategy that has been a proposed for Indigenous student assessments in Australia. The framework for PLPs is generally recommended to be designed in ways that involve community and parents in the assessment and learning practices, and extending teacher participation within the community (Klenowski, 2014). Effective PLPs improve student assessment outcomes as they articulated based on students' individual goals, aspirations, health and wellbeing, spiritual and emotional connections, and personal subjectivities. Students' own their learning pathway and have opportunities to exercise agency in the development, monitoring and review of their learning processes. However, research shows that the conceptualisation and implementation of PLP varies greatly across states. Klenowski (2014) points to the differences in PLP design that result in varying outcomes across schools, communities and states and highlights that the effects of PLP on Indigenous student learning outcomes, while promising, are still a work in progress.

In a more recent example for STEM education, Dupuis and Abrams (2017) observed that Indigenous students performed better in assessments that tested both Indigenous science knowledge alongside mainstream/Western science knowledge. Similarly, Grootenboer and Sullivan (2012) found that task-based interviews were an effective way to assess Indigenous students' maths knowledge, particularly by framing questions in a way that drew upon students' cultural and place-based awareness (for e.g., measuring distance to the river).

Across a range of research on Indigenous assessment practices, the linguistic codes, conventions and connotations embedded in assessments have also been highlighted as a critical aspect. Assessments are generally designed using standard English, which is just one element in the Indigenous linguistic repertoire. While pedagogical approaches such as 'Two-Ways' and 'Both-ways' learning models adopt a bilingual/multilingual teaching and learning methodology, standard English continues to remain the predominant language of assessment design. Malcolm (2011) defines three linguistic elements that need to be considered in relation to Indigenous assessment standards. Firstly, there needs to be an acknowledgement of the diversity of languages and a consideration of how assessments can be delivered in a multilingual context. Secondly, speakers of Aboriginal English are often assumed to be able to learn through Australian English. This often becomes problematic when standard English is encouraged over or placed in opposition to Aboriginal English which has its own rules and structures in relation to aspects such as kinship, body language, questions, endings, sounds, grammar, meanings and quotes

amongst others (see for example: Butcher, 2008). Finally, many Indigenous people are not experiencing the same socio-cultural contexts and day-to-day language registers as non-Indigenous people, which can create issues of translation around how assessments are defined or explained.

Indigenous excellence and high expectations

It is well documented in academic and non-academic literature that educators have traditionally held low expectations from Indigenous students and their communities. Indigenous people continue to be heavily impacted by a "deficit colonial gaze", due to which they often accept negative stereotypes as part of their identity further perpetuating low expectations from self and others (Tynan & Noon, 2017 p. 16). The deficit framework posits that Indigenous students are less likely to have positive learning outcomes compared to their non-Indigenous counterparts due to their external situation which involves language, socio-economic and other socio-cultural disadvantages (Sarra et al., 2018). While awareness around the negative educational impacts of such deficit positioning of Indigenous students has improved, there are still inconsistencies in understandings of its impact and the need for deeper recognition of its structural workings. In many instances of policy and government initiatives as well, Indigenous students have been situated in a position of having to "catch up" with the prevailing educational culture (Fahey, 2021). Sarra et al. (2018) caution that when a society is so deeply conditioned to a Western educational culture, it becomes difficult to have equal expectations of Indigenous students (and other minority groups). For a more equitable application of student excellence and academic expectations, schools need to delve deeper to explore the strengths and values that Indigenous students, their families and cultures bring to the classroom.

High expectation relationships in Indigenous STEM education

Recent work by Sarra et al. (2018) has been influential in highlighting crucial differences between a 'high-expectation rhetoric' and 'high expectation relationship' in schools. The former is based on the deficit model discussed above, and frames Indigenous students' position as one that needs to be 'caught up' to meet high expectations. The latter focuses on "developing relationships that connect teachers and students through a shared humanity" (Tynan & Noon, 2017, p. 17). The framework that Sarra et al. (2018) present situates high expectation relationships at the intersection of educators and education systems: "understanding personal assumptions, creating spaces for dialogue, and engaging in challenging conversations" (p. 35).

Research explored for the purpose of this review has illuminated that following a pedagogic reframing is a necessary first step. Taylor (2012) for instance, poses an important question: how can we ensure effective education of science and mathematics *for* all unless we are inclusive of science and mathematics *of* all? Using a relational framework, educators can assess, for example, to what extent their personal values and beliefs are inclusive of Aboriginal and Torres Strait Islander students' contextualised interests in science and mathematics. McConney et al. (2011) suggest that non-Indigenous science and maths educators need to become "culture-brokering" science and maths educators who acknowledge Indigenous students' unique dispositions and worldviews, and then find ways to make meaningful cultural connections (p. 2029). Educators can create spaces for critical and reflective understandings of the intersections of Western and Indigenous perspectives for STEM through discourse and yarning circles. Such approaches can then challenge the "false dichotomy" (Nakata, 2002, p. 284) between mainstream and Indigenous knowledge systems, and allow all knowledges to develop through constant discourse and interactions with each other. For schools and classrooms to become spaces of such critical interaction, teachers need ongoing professional development that focuses on the ways in which Indigenous and Western teaching models can co-exist and evolve with each other. The sections below provides examples from empirical research of teacher PL initiatives that incorporate high expectation and culturally responsive values.

Teacher professional learning

Teachers' professional development continues to receive increasing scholarly attention as STEM pedagogical frameworks develop and evolve. However, teacher's professional development in the context of Indigenous STEM has received scant attention. Most empirical work that explores

the effectiveness of teachers' PL emphasises on indicators such as teaching practices or student outcomes. However, as Craven et al. (2014) point out, Indigenous teaching needs to examine PL practices across multiple indicators that gauge teachers' understandings of culturally appropriate ways of teaching including Indigenous values, concepts, histories and positionalities. PL also needs to be guided by Indigenous community members and Elders to understand Indigenous ways of inculcating concepts and ideas into teaching practices.

One approach for effective Indigenous PL has been offered in research conducted by Santoro et al. (2011) who suggest that Indigenous educators, who have also been Indigenous learners, can play an important role as trainers and mentors for non-Indigenous teachers through developing understandings of Indigenous ways of knowing; Indigenous learners' out-of-school lives; and the importance of building relationships within and beyond the school. An example of this approach within the STEM context is the YuMi Deadly Maths (YDM) model developed by Aboriginal mathematician Chris Matthews, which is delivered as a professional development session to selected teachers by the YuMi Deadly Centre (YDC) at the Queensland University of Technology. Teachers are trained to "see connections between mathematics ideas, to sequence from one idea to the next, and to focus on 'big' ideas as part of high expectations methodology" (Tynan & Noon, 2017, p. 34). The program follows a train-the-trainer model where teachers first learn to implement the approach in their classrooms and then train other teachers on the pedagogy. YDM has also provided opportunities for educators to engage with parents and communities through activities such as maths fiestas, demonstration days, and engagement sessions to train families on engaging students in maths activities at home[9].

A second more macro level approach is the implementation of institutionalised forms of training and development for teachers at a national scale. An example of this approach is *Primary Connections*, a flagship national primary school science teaching and learning program developed by the Australian Academy of Science and supported by the Australian Government Department of Education, Skills and Employment. *Primary Connections* has developed an Indigenous Perspectives Framework in collaboration with a number of Aboriginal and Torres Strait Islander educators, consultants, linguists and representatives. Drawing upon six organising ideas that focus on curriculum, cultural diversity, relationships and partnerships, quality teaching and learning, students' worldviews, and teachers' worldviews, the framework provides an array of resources and guidelines to assist teachers in generating interest, discussion and exploration of Aboriginal histories and cultures through the context of science. External evaluation of the program has demonstrated that the program has been successful in improving teachers' confidence, enjoyment and understandings around teaching Indigenous perspectives for STEM education (Hackling & Prain, 2005).

Limitations and challenges

The various examples of empirical research in the above section provide valuable insights on the ways in which Indigenous pedagogical frameworks can be incorporated in teachers' professional development practices. However, it is also important to consider that these PL practices need to be ongoing and continuing, rather than one-off or stand-alone training initiatives. Researchers in this domain have also cautioned against viewing these approaches as a single solution to the context of Indigenous STEM education which can be complex and multifarious because of the following reasons.

Firstly, Indigenous Peoples are not a culturally homogenous group. Indigenous teachers' and students' positionalities can vary significantly depending on where they are, their traditional Country, their heritage, community, and cultural practices. As such, their STEM pedagogies can vary as well, as represented by the different frameworks identified earlier in this literature review. These differences need to be considered when designing PL involving both Indigenous and non-Indigenous contributors. Santoro et al. (2011) caution that assuming Indigenous teachers know "everything there is to know about Indigenous learners and Indigenous cultures" is a common trope that needs to be avoided (p. 73). This also does not suggest that non-Indigenous teachers know little about Indigenous cultures. Furthermore, establishing Indigenous teachers as mentors tends to put additional responsibility on them to bridge the

[9] *A full list of the YuMi Deadly Centre Impact evaluation reports is available here:* https://research.qut.edu.au/ydc/about/evidence-of-effectiveness/

gap between Indigenous and non-Indigenous communities. Without proper recognition of the importance of their knowledge and expertise, adequate time allowances, and acknowledgements of their work, Indigenous mentoring programs can become too onerous for Indigenous educators.

Secondly, it is important to consider that Indigenous educators, especially in STEM fields are significantly underrepresented in the Australian teaching landscape. This means that opportunities to engage them in formal mentoring or pedagogical consulting are limited. Most Indigenous educators are working in schools where there are higher populations of Indigenous students. As a result, their knowledge and expertise are usually applied in those contexts and passed on to only a small number of non-Indigenous teachers. For a more mainstream adoption of Indigenous STEM pedagogies, there is need for ongoing initiatives and collaborations across regional, local and national scales.

Some researchers like Hynds et al. (2016) have also noted that care needs to be taken in how Indigenous PL and pedagogical training is positioned. Oftentimes it can be seen through a deficit-oriented lens as "remedial work" rather than authentic teaching practices that should be implemented alongside Western STEM perspectives. Such perceptions can tend to shift the focus from "culturally underperforming schools" to the problematic rhetoric of "underachieving Indigenous students" (p. 241). PL therefore, needs to encourage teachers to be more reflective and considerate of such long standing biases in the prevailing education system.

Beyond the classroom: extended learning and links with industry

Numerous authors have argued in favour of bringing Indigenous ways of thinking and doing into the STEM industries ranging across agriculture, environmental science, media and design and digital technology (e.g. Abdilla & Fitch, 2017; Capel, 2014; Macdonald et al., 2021). By integrating Indigenous knowledges into STEM industry-community partnerships, there are benefits not just in relation to Indigenous career pathways, but for entrepreneurship and innovation as well. Indigenous knowledges have long been vital in land and sea management practices, but have recently also been valuable in the area of climate science. Research by Memmott et al. (2013) for example observed how Aboriginal people's close understandings of the natural environment enabled strategies of adaption to climate change and climatic events such as cyclones. Practices of 'being on Country' through harvesting water from trees, preserving food, and learning about nutritional values of bushfoods, for instance, are valuable knowledges that can inform current government and non-government policies, projects and agendas in areas of agriculture, ecology and environmental sustainability.

In other work, Broffman (2015) traces developments in Australian design history and argue for a rethinking of contemporary understandings of communication design that is largely focused on Western Eurocentric notions of design thinking. They demonstrate how Indigenous design developments offer rich iconographic forms of visual language, storytelling and narration that can act to disrupt modern ideas of visual communication design. Similarly, Macdonald et al. (2021) argue that current 'human-centred' notions around responsible product and service design, where researchers develop products and technologies in collaboration with users, can learn valuable lessons by incorporating Indigenous ethics and protocols in design practices. Their research shows that by considering the "relational paradigms and mutual respect that are embedded in Indigenous relationships with kin and Country" alternative approaches to technology design can be illuminated that are beneficial to people and the environment, beyond simply serving "functional goals and addressing technical problems" (p. 13). Others like Abdilla and Fitch (2017) identify the potential and profound implications of Indigenous "Pattern Thinking" embedded in "Indigenous Traditional Knowledge (ITK)" (interconnectedness of human, non-human and nature) in the use and development of emerging digital technologies such as Robotics and Artificial Intelligence (p. 1). Specific empirical examples of the intersections of Indigenous STEM with digital technologies are explored in the following section.

DIGITAL TECHNOLOGIES AND INDIGENOUS STEM

The discussion within preceding sections of this literature review has briefly touched upon some examples of the use of digital technologies in Indigenous STEM education. In this section, however, we focus specifically on literature and case studies of Indigenous STEM education that are germane to the stem.T4L project. Operating in NSW public schools since 2018, stem.T4L provides students and teachers the opportunity to use one of eight kits for the duration of one school term. The kits include a range of digital learning material and tools that promote the NSW DoE's 'future-focused learning' agenda that empowers schools to teach students to solve the problems of tomorrow. These kits provide schools the opportunity to enhance teaching and learning with cutting edge digital technologies such as virtual reality, 3D printing, filmmaking, 360° video and imaging, coding and robotics. However, as cautioned by Herodotou et al. (2019), the intersections of digital technologies with Indigenous learning pedagogies need to be handled sensitively, as the use of, and prompts and actions stemming from digital devices may be seen as culturally inappropriate in certain community-based learning contexts. Therefore, the discussion in the subsequent sections on the use of emerging digital technologies in Indigenous STEM settings touches on two aspects: (i). It provides useful empirical examples of meaningful applications of digital tools and media technologies in Aboriginal and Torres Strait Islander educational contexts, and (ii). It opens up a space for reflection and consideration on how emerging digital technologies can be practically and authentically embedded within Indigenous STEM pedagogical frameworks.

Augmented and virtual realities

Although AR and VR technologies have only scarcely been implemented in Indigenous educational settings, research on broader applications of VR technology to Indigenous language, culture and heritage provides useful contextual insights. For instance, Marques, McIntosh and Carson (2019) engaged with *Ngati Kahungunu ki Wairarapa*, a Maori *iwi* (tribe), to reimagine and represent the oral narrative traditions of Aotearoa New Zealand's landscape through the merging of existing landform and AR. More recently Wallis and Ross (2021) outline the ways in which Indigenous creators are using VR tools and techniques to tell their stories amidst Eurocentric modes of media production and distribution, express and imagine Indigenous futures, foreground native languages in virtual worlds and provide new articulations of Indigenous activism. These diverse applications of AR/VR technology for storytelling, imagination, creativity, critical thinking are aspects that are central to the pedagogic objective of teaching and learning with new media technologies.

Irving and Hoffman's (2014) report on the *Nyungar Place Stories* pilot, although centred on undergraduate students, nonetheless highlights the potential for using AR in place-based, On-Country learning methods. Elders from the local Nyungar community were recorded telling stories that described the social and environmental features of significant sites. Non-Indigenous health students from a Western Australian university were then provided with an AR smartphone app, where they could listen to these stories and learn additional information that was overlayed on the area via the app. The authors report limited uptake from students, due to problematic roll-out and limited PL or awareness for teachers. However, should such issues be addressed, the project demonstrates the value of synthesising place-based learning with contemporary technology (Irving & Hoffman, 2014).

As a vehicle for story-telling, AR has also been found to be valuable for encouraging greater bicultural engagement in indigenous culture. Diverse approaches by researchers in this domain have opened spaces for valuable '(re)storying' and 'counter-storytelling' that seek to reveal new narratives based on Indigenous truths and perspectives on erased histories (McMahon et al., 2019; Almond et al., 2018). Others such as Wallis and Ross (2020) show how an "Indigenous-centred VR production framework" can challenge or resist dominant Eurocentric modes of digital production (p. 313). Furthermore, the use of relevant localised and contextualised digital assets extends renewed forms of Indigenous teaching and learning through the help of AR tools and technologies (Mac Callum & Jameison, 2018).

Coding and Robotics

Coding and robotics are emergent components of STEM curriculum globally, and are beginning to be employed in a variety of Indigenous education contexts that enmesh cultural learnings of language, geography, history and heritage with STEM subjects and concepts. Abdilla and Fitch (2017) for instance, report on the Indigenous Robotics Prototype Workshop, conducted with Indigenous students at an inner-Sydney public school. Through consultation with a local Gadigal Elder, the workshop began with an introduction to Indigenous knowledge systems and the corollaries with learning coding, situated in understandings that "both coding and territory adhere to certain protocols" (Abdilla & Fitch, 2017, p. 4-5). After mapping local Country (such as the boundaries of Gadigal, Dharug, Dharawal and Guringai lands), students completed navigation exercises using Lego Mindstorms kits, learning to program a robot so that it follows a journey across Country. While the authors report limited evaluation data and note the need for further study in this area, they describe how the workshop "achieved a sense of cultural pride and confidence in Indigenous traditional knowledge while inspiring the youth to continue with their engagement in coding and programming through building robots" (Abdilla & Fitch, 2017, p.1).

A more recent example comes from Keane et al. (2019) who investigate the impacts of humanoid robots on students' learning and engagement. In the case of this study, Aboriginal and non-Aboriginal students worked together to develop, in parallel, both their programming skills to build the robot, and their traditional Narungga language and culture skills. The study found that students developed 21st Century skills, computational thinking skills, and demonstrated a heightened sense of engagement and curiosity, challenging assumptions about students' learning potentials and educators' beliefs and methodologies for pedagogy in the field of digital technology.

Film and production

Apart from contextual parallels that can be drawn from research on the role of VR and AR content creation in Indigenous STEM education, important insights can also be drawn from empirical work on the role of film and production by Aboriginal students situated within the realm of media, literature and cultural studies. For example, research conducted by Mills et al. (2013) narrates the experiences of sensory and embodied learning experiences through digital media production by Indigenous school students. Incorporating Indigenous understandings of place and Country through documentary film making at the intersection of English and film-making units, they argue that literacy practices not only occur in the mind, but are also experienced through sensory engagement with people, places and local ecologies. Their study found that through different aspects of digital media production (capturing images, recording information, filming, editing, conducting interviews, uploading footage, critiquing frames etc.) students were able to achieve a deepening awareness of their realities and how they may be able to transform them and their communities.

Another example includes work by Stanton et al. (2020) who found that practices of digital 'storywork' in film and media production, particularly for Indigenous students provides not only an opportunity for student-centred pedagogy, but also a means for authentic representations and reflections of Indigenous identity and life. Their study found how digital storywork through film making provided "robust learnings" about other critical subjects such as geography, civics, history and economics (p. 56). As such, they conceptualise Indigenous digital storywork as a powerful framework to support methodological and pedagogical contributions to K-12 education.

3D printing

Empirical examinations of 3D printing technologies within Indigenous schooling communities appear to be negligible in academic literature. One exception includes a recent pilot study by Rioux et al. (2019) who explores the ways in which Aboriginal preservice teachers on the Northern Territory's Tiwi islands can apply their local traditional knowledge to the learning and teaching of Western mathematical concepts using 3D technology. Proposing to use a 3D model of Tiwi Islands created from satellite images, they suggest ways in which teachers can embed place-based learning and Indigenous ways of knowing to engage students and achieve specific mathematics curriculum goals. They provide examples of rich localised tasks that can be used

to develop mathematical concepts, for instance, measuring and converting distances between two sacred sites.

Some insights can also be drawn from media reporting on the ways in which Indigenous communities have incorporated the use of 3D printing within their local contexts. For instance, how a remote Indigenous community on Milingimbi – an island off Arnhem Land east of Darwin – converted its plastic waste into sunglasses, phone cases and toys using 3D printing, received enthusiastic media coverage nationally (Terzon, 2015). The initiative, dubbed as 'Project Plastic Fantastic' also increased students school attendance in the community while generating interest in topics and issues such as waste management, technological solutions, and creativity and innovation while touching on STEM educational concepts (i.e. measurement, analysis, sustainability etc.). 3D printing, also known as 'additive manufacturing' has also been argued to revolutionise remote and rural communities through facilitating quick and localised supply of goods such as parts in farming equipment, medical equipment and so on (Sammartino, 2016 as cited in The Guardian, 2016). Making 3D printing technologies accessible and developing skills in utilising them, can therefore, be of critical economic and social importance to rural Indigenous communities.

CONCLUSION

Through this narrative literature review, we have demonstrated that STEM teaching and learning is not only a key educational agenda for Indigenous communities, but its application has been pragmatically and meaningfully embedded in diverse Indigenous scientific practices for millennia. STEM knowledges and practices of Indigenous Australian communities are now being rediscovered and revitalised in research and in real-world industries - from the application of Aboriginal pyrotechnics to various land and sea rehabilitation projects. Through engagements with emerging scholarship and policy developments, this literature review has also established that Indigenous STEM is complementary to mainstream/Western STEM based on its strong empirical basis, STEM traditions and pedagogy, and parallels with domains of digital technologies and the computer sciences such as abstraction, algorithm and pattern recognition (Tynan & Noon, 2017).

We further call attention to core Indigenous pedagogies that incorporate conceptual and contextual elements of Indigenous experiences and outline empirical examples of these frameworks in practice, particularly for STEM education. The frameworks we highlight include cultural-identity based pedagogy, non-verbal, narrative based and reflective learning (8Ways), 'Two-Way' learning or dual epistemology, and On-Country approaches. Each of these frameworks draw upon the unique experiences of Indigenous communities and students, and have demonstrated profound impacts in the contexts within which they have been applied. Examples include CSIRO's *Science Pathways* and *Two Ways Science* approach as initiatives that connect Indigenous and Western STEM methods in authentic ways to advance STEM outcomes for both Indigenous and non-Indigenous students. Work by CSIRO (amongst others) also emphasises that these pedagogies not only engage Indigenous students in STEM education, but must also be used as important resources to embed Indigenous STEM in mainstream interdisciplinary education.

Pedagogies alone, however, can be inadequate in addressing long-standing gaps between Indigenous and non-Indigenous education outcomes. Furthermore, Eurocentric science perspectives tend to ignore or devalue notions of Indigenous knowledges and (scientific) vocabularies (Abrams et al., 2018). Literature suggests that educators and stakeholders, therefore, need to be mindful of broader considerations to ensure that Indigenous STEM outcomes are achieved in a holistic way. Drawing upon scholarly work at the intersections of Indigenous education, Aboriginal students' STEM engagement and pathways, and educators' professional development, we highlight that initiatives, strategies and programs dealing with Indigenous STEM education must consider cultural responsiveness; appropriate assessment; maintenance of high expectations; suitable PL for teachers; and avenues for partnerships beyond the school through links with the wider community, industry and the higher education sector.

Finally, our aim with this literature review was to uncover some of the ways in which *education* with and *education on* Indigenous STEM is advancing through new digital technologies. While there is paucity of research in this area, our method of conducting a narrative literature review allowed us to cast the net wider and examine literature from other contextually relevant domains such as the use of digital technologies in Indigenous higher education, international applications, and reports in media outlets. Indigenous knowledges are generally believed to be fundamentally at odds with growing demands for digital advancements within Western education systems. However, our investigation uncovers fascinating examples of research, programs and interventions that have resulted from the use of technologies such as AR and VR, coding and robotics, film and production, and 3D printing for Indigenous STEM education. From counter-storytelling to Country-mapping, sensory and embodied educational experiences to waste management, emerging digital technologies demonstrate great potential for Indigenous Australian culture and communities. At the same time, Indigenous STEM pedagogical developments and examples of technological applications also provide meaningful contributions to the advancing field of STEM education itself.

While more research on the development and use of digital technologies in Indigenous STEM education is certainly needed, future research in this area can further engage with questions around how Indigenous knowledge systems might "hint towards a possible paradigm shift" for the design and application of new technologies (Abdilla & Fitch, 2017). Other possibilities also include examinations of ethical development and use of digital technologies in Indigenous STEM education; teaching methodologies and encounters; and Indigenous STEM career pathways. As such, this literature review can serve as a springboard for further discussion and possibilities of the multifarious role of Indigenous pedagogies, knowledge systems and methodologies in future research, design and utilisation of digital technologies in K-12 education.

A resource guide for educators with information in Indigenous educational frameworks, best practices, professional learning and development, and other supplementary resources has also been created and can be accessed here.

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