30 November 2023

Big Mob: STEM it Up Research Report

“S.T.E.M in Community” by Tara-Rose Gonebale.

Big Mob: STEM it Up Research Report 2023

First published November 2023

Recommended citation: Shay, M., Miller, J., Thomson, A., Cole, A., Hameed, S., Perkins, R., Rashidi, P., Hurley, A., Ockerby, Z, Harvey-Smith, L., & Williams, L. A. (2023). *Big mob: STEM it up research report 2023*. The University of Queensland. ISBN: 978-1-74272-425-6.

Table of contents

List of tables

List of figures

Acknowledgements

Funding

This study was funded by the Office of the Australian Government's Women in STEM Ambassador to inform the Pathway to Diversity in STEM Review.

Ethics approval

Ethical approval was granted through The University of Queensland (2023/HE000527).

Graphic design

"S.T.E.M in Community" by Tara-Rose Gonebale.

"This artwork depicts the importance of collaboration between Indigenous communities and Non-Indigenous communities within the field of Science, Technology, Engineering and Mathematics. It speaks to the traditional ecological knowledge of Indigenous people, and how it can be integrated into modern practices of today."

Artist Biography: Tara-Rose is a proud Wagiman Woman from the Western Suburbs of Naarm (Melbourne). She has been an exhibiting artist from as young as 8 years of age and has worked in Aboriginal community services for the last 10 years. Tara is currently working with mob in the correctional space as an Aboriginal Mental Health Worker.

Acknowledgement from the research team

We want to acknowledge Aboriginal and Torres Strait Islander peoples and recognise their sovereignty, diversity, strength, and excellence. We thank everyone who participated in the study and shared their invaluable insights and stories throughout the project. We acknowledge and thank the Office of the Australian Government's Women in STEM Ambassador for ensuring there was a distinct place in exploring Indigenous participation in STEM and how to build from the existing strengths and mob who are already trailblazing in diverse STEM fields.

About the research team

Associate Professor Marnee Shay is an Aboriginal academic whose people are from Wagiman Country (Daly River region Northern Territory). She was born in Brisbane and has strong community connections throughout Southeast Queensland. Marnee is a Principal Research Fellow at The University of Queensland. Marnee is an established research leader with an extensive externally funded research program that spans Indigenous education, Indigenous policy, and flexi schooling. Marnee is a Chief Investigator at the ARC Centre of Excellence ‘Indigenous Futures’ 2023-2029.

Associate Professor Jodie Miller is a non-Indigenous education researcher working as an Associate Professor at The University of Queensland. Before working in universities, Jodie was a primary classroom teacher. Her research focuses on improving teaching and learning in mathematics and STEM, particularly for students who are most at risk of marginalisation from the school curriculum. In addition, her recent research collaborations focus on examining excellence in Indigenous education.

Amy Thomson is a proud Aboriginal woman living in Brisbane, with maternal connections to Mandandanji Country, and is currently undertaking her PhD at The University of Queensland. Amy’s research focuses on the English curriculum; co-design; and how Aboriginal and Torres Strait Islander cultures, histories, and perspectives can be embedded in private schools. Amy currently works as a Senior Research Assistant and teaches undergraduate students at The University of Queensland in the School of Education and the Aboriginal and Torres Strait Islander Studies Unit.

Antoinette Cole is a proud Torres Strait Islander descendant, with her family connections to Boigu Island and Erub (Darnley) in the Torres Strait. Antoinette leads with her heart to inspire hope and a shared vision among her colleagues. She advocates for a future where reconciliation endures, where improvements in learning and teaching pave the way for equitable opportunities for First Nations staff and students to achieve and celebrate success. She has demonstrated outstanding service within and beyond the Catholic Education community for almost 30 years and shows integrity as a formidable leader. Antoinette is currently undertaking her PhD at The University of Queensland, focusing on Culturally Responsive School Leadership.

Dr Suraiya Hameed is an interdisciplinary leader, educator and researcher specialising in Educational Leadership. She researches within the areas of Educational Leadership; Global Policy and Education; and Equity, Inclusion, Diversity and Culture. Dr Hameed’s research projects aim to make that major breakthrough in the development of leaders supporting the schools of the 21st century. She is currently leading multiple international research projects which aim at engagement with international counterparts to improve educational outcomes and to generate networking opportunities with international educators and school leaders.

Ren Perkins is a Quandamooka man with connections to the Wakka Wakka Nation. He is a Postdoctoral Fellow at The University of Queensland. His PhD research topic was learning from the lived experiences of Indigenous teachers who have remained in the profession. Ren has worked in Indigenous education for over twenty years. His research to date has emphasised strengths approaches and centring of Indigenous voices and stories.

Dr. Pedram Rashidi is a science and technology researcher with a Master of Science in physics, extensive work experience in industry, and a PhD in the political science. His scholarship concerns science and technology policy, development and environmental politics, and Indigenous environmental studies. He teaches undergraduate and postgraduate courses in social and political sciences at The University of Queensland.

Amanda Hurley is a non-Indigenous Senior Research Assistant at The University of Queensland. Her research interests are in world religions and spiritualities, with a focus on ecotheology. Her skills in writing and project management have supported the project across the podcast, literature review, international case study, and survey outputs.

Zoe Ockerby is a Research Assistant and PhD candidate at The University of Queensland. Her research interests are in the areas of developmental and evolutionary psychology. Specifically, her research looks at innovation and future-oriented thinking, and how this affects decision-making. Zoe has expertise in survey design and both quantitative and qualitative data analysis.

Professor Lisa Harvey-Smith is an astrophysicist, the Australian Government's Women in STEM Ambassador, and a Professor of Practice in Science Communication at University of New South Wales. Her role is to increase the participation of women and girls in STEM (science, technology, engineering, and mathematics) studies and careers in Australia by driving systemic and cultural change.

Associate Professor Lisa A. Williams is a social psychologist whose research explores how emotions shape and are shaped by social processes. She is an advocate for equity and diversity in STEM, and currently serves as Associate Dean, Equity, Diversity and Inclusion in the Faculty of Science at The University of New South Wales. Lisa has brought the context of the Pathway to Diversity in STEM Review to the project.

Executive summary

This report presents findings from the *Big Mob: STEM it Up* research project. This research was commissioned as part of the Pathway to Diversity in STEM Review by the Office of the Australian Government's Women in STEM Ambassador (Australian Government, 2022). Addressing equity and inclusion in STEM participation rates was a key mandate of the Pathway to Diversity in STEM Review (Australian Government, 2022). This research focuses on Aboriginal and Torres Strait Islander participation in STEM, as well as understanding how Indigenous STEM knowledges are incorporated in Western knowledge paradigms as this is highly interconnected with the focus of Indigenous participation in STEM. As Indigenous knowledges have existed in this Country for at least 65,000 years (Department of the Prime Minister and Cabinet, 2018), understanding the recognition and value of Indigenous STEM knowledges and the increasing interest in these knowledges is critical and timely. This research consolidates the literature in two fields to date: Indigenous knowledges in STEM and Indigenous participation in STEM. While both topics are highly interrelated, they are also distinct.

This report uses the terms Aboriginal and Torres Strait Islander peoples and Indigenous peoples interchangeably. The authors acknowledge the diversity in language preferences of Indigenous peoples as well as the cultural and linguistic diversities of Aboriginal and Torres Strait Islander peoples nationally.

Aims

The *Big Mob: STEM it Up* research project aims to inform evidence-based strategies for enhancing the participation of Aboriginal and Torres Strait Islander peoples in science, technology, engineering, and mathematics (STEM) fields. The project uses a multimethod approach, incorporating Indigenous methodologies such as yarning (Bessarab & Ng'andu, 2010) and community-based sampling (Woodley & Lockard, 2016). The project is also underpinned by Rigney's (1999) three Indigenist research principles: privileging the voices of Indigenous peoples; resistance as the emancipatory imperative; and political integrity. The multimethod approach resulted in four research outputs:

- two systematic literature reviews
- a community-based survey
- qualitative interviews (published as a podcast)
- three international case studies on effective approaches to increasing Indigenous participation in STEM.

In addition to generating high quality and rigorous evidence through research to inform the Pathway to Diversity in STEM Review, it was also important to consider the principle of reciprocity in undertaking Indigenous focused research (AIATSIS, 2020). This research was committed to the principle of reciprocity and thus produced a podcast series that is a resource for Indigenous communities longer term. The podcast series is a resource for Indigenous peoples and communities through highlighting strengths-based success stories of Indigenous peoples who are trailblazing in their fields. Forthcoming outputs from this research will be open-access where possible, to ensure the findings are shared widely throughout the Indigenous community and the broader community as well.

Report overview

The report structure outlines the research design and then reports on findings from each program of research: systematic literature reviews, community-based survey, qualitative interviews, and international case studies. The report concludes by reporting on a synthesis of all findings that resulted in 22 key findings and 15 recommendations.

Key findings

The research undertaken as part of the *Big Mob: STEM it Up* project has resulted in 22 final key findings (see **Table 1**).

Table 1
Key Findings From the Big Mob: STEM it Up Research Project

Key findings
Key finding 1: Most knowledge about Indigenous participation in STEM or Indigenous STEM knowledges is produced by non-Indigenous researchers.
Key finding 2: The recognition and valuing of Indigenous STEM knowledges was identified across the data as critical for advancing Indigenous participation in STEM and advancing Western STEM fields.
Key finding 3: Science dominated the data in this research. When investigating Indigenous participation in STEM, it was evident that there has been a narrow emphasis on science, and that technology, engineering and mathematics are areas for development.
Key finding 4: The existing identified literature on Indigenous participation in STEM is small and relatively recent (emerging in the past 20 years).
Key finding 5: Just under one-quarter of Indigenous participants from the survey data reported that they did not know what STEM meant or was. This finding provides key evidence for future approaches to increasing Indigenous participation in STEM.
Key finding 6: The evidence showed a significant lack of scholarly and independent evaluations of Indigenous STEM policy and program interventions.
Key finding 7: Existing research focused heavily on Indigenous participation in STEM in education contexts. The data from Indigenous people in this study showed that the greatest influence, on their interest and study/careers in STEM, is from their family and community.
Key finding 8: A body of the identified research focused on remote community settings, but there is a gap in regional and urban settings.
Key finding 9: Most Indigenous people who contributed to this research reported an interest and positivity toward the possibilities of STEM individually, and for their communities.
Key finding 10: The systematic literature review highlights mostly educational barriers to Indigenous participation in STEM. The survey data showed different barriers identified by diverse Indigenous people. These were ranked accordingly: 1) institutional barriers such as

racism; 2) individual support and self-confidence; 3) affordability; 4) awareness of STEM; and 5) educational barriers.

Key finding 11: Mentoring was important across all data. One new aspect of mentoring to emerge was the significance of family and community as a source of guidance, inspiration, and support.

Key finding 12: Indigenous STEM initiatives were spoken about positively across the data. These appear to have a positive impact for some Indigenous people.

Key finding 13: International studies from New Zealand, Canada, and the United States of America (Alaska) showed that applied approaches and hands-on learning appear to have positive impacts on increasing Indigenous participation in STEM.

Key finding 14: International case studies demonstrate the importance of Indigenous input into program design.

Key finding 15: The issue of educational barriers surfaced in all data. The barriers are connected to broader Indigenous education imperatives such as the overall goal to deliver positive educational outcomes for Indigenous peoples.

Key finding 16: There is limited literature on Indigenous STEM recruitment, retention, and researcher development in higher education.

Key finding 17: The evidence produced in this research shows a significant gap in industry-based research and Indigenous participation in STEM.

Key finding 18: The evidence produced in this research shows that programs and research on Indigenous participation in STEM, undertaken collaboratively and using co-design approaches, support better outcomes.

Key finding 19: There is a gap in research on the role of the Indigenous business sector and Indigenous participation in STEM.

Key finding 20: As there is limited research overall on the topic of Indigenous participation in STEM, there was limited identified research investigating other forms of diversities within the Indigenous population and the impacts on their participation rates in STEM.

Key finding 21: The evidence showed that there is a very limited body of research that includes the voices of Indigenous young people. The *Big Mob: STEM it Up* research did not have the capacity to include young people in this study, so this gap remains.

Key finding 22: There is very limited research that explores Indigenous STEM engagement in the early years.

Recommendations

The 22 key findings resulted in 15 recommendations to the Australian Government with the goal of increasing Indigenous participation in STEM (see **Table 2**).

Table 2
Recommendations to the Australian Government

Recommendations	Key finding (KF) alignment
Recommendation 1: Development of a national program to increase Indigenous STEM researchers. The field of STEM requires Indigenous peoples to advance Indigenous knowledges. It is currently unknown how many Australian universities employ Indigenous STEM researchers or whether STEM higher degree research pathways are encouraged by universities. An investment in consolidating and understanding the current cohort and planning for supporting an increased Indigenous STEM workforce is urgently needed, as it is strongly connected to the overall goal of increasing Indigenous participation in STEM.	KF 1, 2, 20
Recommendation 2: Advancing Indigenous STEM knowledges. The criticality of recognising, valuing, and advancing surfaced across all data. Both Indigenous peoples and Western scientists advocate for advancing Indigenous STEM knowledges for the benefit of the field, as well as in the quest to increase Indigenous participation in STEM. Advancing Indigenous knowledges requires research investment and university-based infrastructure to develop a cohesive approach. Advancing Indigenous knowledges should also include a clearinghouse of trusted sources for educators (school and university-based) in embedding Indigenous STEM knowledges in curricula.	KF 1, 2, 20
Recommendation 3: Urgent investment in Indigenous participation in technology, engineering, and mathematics. The evidence demonstrates an emphasis on science in understanding Indigenous participation in STEM. Policy and program interventions should be developed to address Indigenous participation in technology, engineering, and mathematics.	KF 3, 4
Recommendation 4: Community-based campaign to increase awareness of STEM. The evidence generated from the *Big Mob: STEM it Up* research demonstrates that some Indigenous people have language and cultural barriers in understanding what STEM is and what opportunities there are to be involved. An Indigenous-led campaign aimed at breaking down barriers is needed to demystify language and create a greater awareness among diverse Indigenous peoples.	KF 5, 18
Recommendation 5: Independent program and policy evaluation. The evidence highlights a gap in rigorous, independent, scholarly evaluation of policy and program interventions on increasing Indigenous participation in STEM.	KF 6

Recommendations	Key finding (KF) alignment
This recommendation includes investigating opportunities for retrospective and future evaluation of policy and program interventions. These evaluations should include Indigenous researchers and funding to resource adequately.	
Recommendation 6: Strengthen relationships between governments, the higher education sector, and NISTEMPN. In 2020, an inaugural gathering of Indigenous STEM professionals formed the development of the National Indigenous STEM Professional Network (NISTEMPN). Much of the evidence outlined in the *Big Mob: STEM it Up* research highlights the importance of Indigenous input into program and policy design. NISTEMPN is an important network in growing Indigenous participation in STEM.	KF 1, 2, 7
Recommendation 7: Creation of a research priority that investigates Indigenous STEM possibilities in urban and regional communities. There is a strong existing evidence base on Indigenous participation in STEM and Indigenous STEM knowledges in remote communities in Australia. The focus on remote communities is at odds with Australian Bureau of Statistics (2022) data that shows only 9.1% of Indigenous peoples live in very remote Australia and 5.4% live in remote Australia. As most Indigenous Australians live in major cities (41.1%), inner regional areas (25.1%) and outer regional areas (18.5%), it is critical that further research explores both Indigenous participation in STEM and Indigenous STEM knowledges where most of the Indigenous population resides.	KF 8
Recommendation 8: Establishment of an Office for Indigenous STEM. Centralising efforts to increase Indigenous participation in STEM would have more impact if the resources and efforts were centralised into an ambassador model like that of the Office of the Australian Government's Women in STEM Ambassador. The international case studies outlined a successful exemplar from Canada, the Saskatchewan Science Ambassador Program (SAP), a unique Indigenous outreach program working between community, industry, schools, and universities. The aim of this model should be to increase Indigenous participation in STEM, monitor data, champion Indigenous STEM knowledges, and inform policy development.	KF 2, 4, 5, 7, 9, 10, 11, 12, 13, 14, 17, 18
Recommendation 9: STEM mentoring programs. Strong evidence supports the value of mentoring at all STEM career phases. Mentors include Indigenous role models, such as Elders and other knowledge holders from Indigenous communities. Developing a mentor program that is Indigenous led for Indigenous STEM professionals who are isolated and want to access mentoring may support recruitment and retention in STEM fields.	KF 11, 12
Recommendation 10: Explore non-traditional pathways to STEM careers. The *Big Mob: STEM it Up* data highlights many examples of Indigenous people identifying STEM skills they used in their family through their cultural knowledge or	KF 9, 17, 18

Recommendations	Key finding (KF) alignment
community. The data also shows that, while most policy or program interventions focus on formal education experiences, Indigenous people are following diverse pathways to undertake professional roles and contribute to STEM fields. These non-traditional pathways could be explored through traineeships, certificate and diploma level qualifications, work experience, and Indigenous business sector employment.	
Recommendation 11: Align Indigenous STEM goals with broader Indigenous education policy imperatives. Educational experiences and broader educational issues such as racism, lack of inclusion of Indigenous knowledges, and socioeconomic factors were raised frequently across the data. Any policy or program approaches to increasing Indigenous participation in STEM should align with broader Indigenous education policy imperatives to strengthen and address broader Indigenous educational disparities.	KF 10, 15
Recommendation 12: Implementation of community-based STEM programs. The data from Indigenous people in the *Big Mob: STEM it Up* research clearly demonstrates the significance of family and community as a strength for Indigenous peoples pursuing STEM education and careers. Therefore, community-based STEM programs to raise awareness of STEM opportunities and existing STEM potential in communities should be piloted.	KF 7, 9, 10, 11, 12
Recommendation 13: Growing industry-based research. There is a clear gap (particularly in technology, engineering, and mathematics) in industry-based research. Industry-based research is vital, as understanding the issue of Indigenous participation in STEM through understanding employer and industry-based contexts provides a deeper understanding of preparing Indigenous peoples for STEM careers.	KF 17, 19
Recommendation 14: Engaging Indigenous young people in understanding problems and solutions. The absence of Indigenous young people's voices in the literature and in this research means there are limited young people's perspectives on Indigenous participation in STEM. Research and policy engagement activities are required to understand Indigenous young people's perspectives on Indigenous STEM and Indigenous participation in STEM.	KF 21
Recommendation 15: STEM awareness from early childhood. Evidence from the data suggests that embedding STEM perspectives into early childhood education provides children with the opportunities to experience STEM from an early age, potentially influencing study choices later in their educational experiences. STEM perspectives should include Indigenous STEM perspectives.	KF 22

References

Australian Bureau of Statistics (ABS). (2022, July 1). *Australia: Aboriginal and Torres Strait Islander population summary*. https://www.abs.gov.au/articles/australia-aboriginal-and-torres-strait-islander-population-summary#:~:text=In%202021%2C%2037.1%25%20of%20Aboriginal,lived%20in%20capital%20city%20areas.

Australian Government. (2022). *Pathway to diversity in STEM review.* Department of Industry, Science and Resources. https://www.industry.gov.au/science-technology-and-innovation/diversity-stem-review

Australian Institute of Aboriginal and Torres Strait Islander Studies (AIATSIS). (2020). *Code of ethics for Aboriginal and Torres Strait Islander research.* https://aiatsis.gov.au/sites/default/files/2020-10/aiatsis-code-ethics.pdf

Bessarab, D., & Ng'andu, B. (2010). Yarning about yarning as a legitimate method in Indigenous research. *International Journal of Critical Indigenous Studies, 3*(1), 37–50. https://doi.org/10.5204/ijcis.v3i1.57

Department of the Prime Minister and Cabinet. (2018). *Closing the gap: Prime Minister's report 2018.* Australian Government. https://www.niaa.gov.au/sites/default/files/reports/closing-the-gap-2018/sites/default/files/ctg-report-20183872.pdf?a=1

Rigney, L. I. (1999). Internationalization of an Indigenous anticolonial cultural critique of research methodologies: A guide to Indigenist research methodology and its principles. *Wicazo Sa Review*, *14*(2), 109-121.

Woodley, X. M., & Lockard, M. (2016). Womanism and snowball sampling: Engaging marginalized populations in holistic research*. The Qualitative Report, 21*(2), 321-329.

Project background

The *Pathway to Diversity in STEM Review* provides recommendations to the Australian Government regarding how change can be supported to ensure access to and a sense of belonging within STEM industries, careers, and education (Australian Government, 2022a). The review aims to engage and hear the stories of Australians who have experiences in STEM business, research, and education. The review also engages with success stories from other countries, evaluates existing programs for women in STEM, and, ultimately, identifies the best ways to improve existing initiatives and develop initiatives for the future (Australian Government, 2022a). It has been identified by the expert panel leading the review that key activities will include: "a research project led by the Women in STEM Ambassador; an evaluation of [the] department's women in STEM programs; [and] engaging with a broad range of stakeholders and the Australian public" (Australian Government, 2022a). Ultimately, the aim of these findings and recommendations will be to improve the participation of underrepresented groups by identifying barriers to retention and participation, as well as key information about the performance of key programs (Australian Government, 2022b). This will address the Australian Government's target for 2030 to have 1.2 million people in technology-related jobs (Australian Government, 2022b). Of note is the requirement to have an increasing number of Indigenous peoples employed in STEM.

Since the *Pathway to Diversity in STEM Review* was announced, there has been increased interest regarding the participation of Indigenous peoples in STEM. Before this review, other organisations such as the Aboriginal and Torres Strait Islander Higher Education Council (ATSIHEAC) have been championing increased Indigenous participation in STEM. ATSIHEAC composed a background paper about Indigenous participation in STEM disciplines and found that, even though there has been growth in the enrolment of Indigenous students in STEM higher education courses recently, this needs to increase exponentially to reach parity not only with non-Indigenous students enrolled but also with other fields of study (ATSIHEAC, 2015). The report revealed that higher numbers of Indigenous students are enrolling in fields such as society and culture, education, and health, impacting what careers they will enter. Low enrolment rates in STEM results in low Indigenous representation in STEM fields (ATSIHEAC, 2015).

There have been challenges for those who do pursue STEM when they enter the workforce. Survey studies have been undertaken to highlight challenges for students entering STEM, such as the *Youth in STEM Research 2019/20* survey (Department of Industry, Innovation and Science, 2020). This survey did not report Indigenous respondent percentages, which means there are limited claims the authors can make about Indigenous youth responses as part of the survey. There appear to be limited larger-scale studies that privilege diverse Aboriginal and Torres Strait Islander peoples' perspectives on STEM.

Contemporary academic literature consistently aligns with the identified needs of the government regarding increasing Indigenous participation in STEM. However, most Indigenous STEM participation research focuses on education, in primary or secondary schooling, K-12 (Jin, 2021; McKinley, 2016), or higher education (Anderson, 2016; Osborne et al., 2019; Trimmer et al., 2018). International research has examined community contexts and how a lack of Indigenous-focused outreach programs in primary and secondary schools can create barriers for Indigenous peoples to participate in STEM disciplines after school (Bonny, 2018). While the schooling experiences that promote and lead to Indigenous participation in STEM, as well as graduation and participation rates of Indigenous peoples in higher education STEM, are valuable, what is noticeably absent in the Australian context is research that examines why Indigenous peoples choose to participate in STEM disciplines as a career, and why they choose to remain in STEM disciplines. There is a lack of surveys focusing specifically on Indigenous participation and retention in STEM disciplines. Additionally, while there has been an internationally focused systematic review on how Indigenous students are supported in science and STEM education (Jin, 2021), more is required regarding the experiences of Australian Indigenous peoples in STEM in industry, community, and education beyond the student experience. This focus requires Indigenous methodologies and Indigenous-designed tools to maximise Indigenous participation and add rigour to the development of Indigenous-based evidence for policy development and enactment (Shay et al., 2022).

The overarching research question which underpinned this study was: How can Australia increase Indigenous participation in STEM fields?

There were four key deliverables for the *Big Mob: STEM it Up* research project:

- A systematic literature review using PRISMA.
- A podcast series showcasing Indigenous excellence in STEM that was used as qualitative data.
- A community-based survey to understand diverse community perspectives on STEM.
- International case studies to understand how other countries have implemented successful policy or program approaches to increase Indigenous participation in STEM.

It is imperative that Aboriginal and Torres Strait Islander peoples are supported in accessing, building capacity within, and participating in STEM education, beyond recruitment, in ways that encourages meaningful engagement and retainment in STEM careers. Therefore, there is a significant gap in research that needs to be investigated regarding why Indigenous peoples pursue STEM careers and why they choose to stay in STEM careers. This project, from an Indigenous standpoint and using a strength-based approach, centered on gathering and sharing the lived-experiences of Indigenous peoples currently in STEM. In addition, it focused on understanding the challenges Indigenous peoples encounter in their pursuit of their STEM careers, to ultimately gain insight, and to share with government to inform future policy, regarding what works and what successfully supports meaningful recruitment and retainment for Indigenous peoples in STEM.

References

Aboriginal and Torres Strait Islander Higher Education Council. (2015). *ATSIHEAC background paper: Indigenous science, technology, engineering, and mathematics (STEM).* https://www.education.gov.au/download/2986/indigenous-participation-science-technology-engineering-and-mathematics-disciplines/4172/document/pdf

Anderson, I. (2016). Indigenous Australians and higher education: The contemporary policy agenda. In A. Harvey, C. Burnheim, & M. Brett (Eds.), *Student equity in Australian higher education: Twenty-five years of A Fair Chance for All* (pp. 221-239). Springer. https://doi.org/10.1007/978-981-10-0315-8_13

Australian Government. (2022a). *Pathway to diversity in STEM review.* Department of Industry, Science and Resources. https://www.industry.gov.au/science-technology-and-innovation/diversity-stem-review

Australian Government. (2022b, November 24). *Review puts spotlight on diversity in STEM.* Department of Industry, Science and Resources. https://www.industry.gov.au/news/review-puts-spotlight-diversity-stem

Bonny, S. M. (2018). Effective STEM outreach for Indigenous community contexts - Getting it right, one community at a time! *International Journal of Innovation in Science and Mathematics Education, 26*(2), 14-34. https://www.proquest.com/scholarly-journals/effective-stem-outreach-indigenous-community/docview/2247805386/se-2?accountid=14723

Department of Industry, Innovation and Science. (2020). *Youth in STEM research – Summary of results 2019/20.* Australian Government. https://www.industry.gov.au/sites/default/files/2020-03/youth-in-stem-research-2020-summary-results.pdf

Jin, Q. (2021). Supporting Indigenous students in science and STEM education: A systematic review. *Education Sciences*, *11*(9), 555. https://doi.org/10.3390/educsci11090555

McKinley, E. (2016, August 8). *STEM and Indigenous learners* [Paper presentation]. Research Conference 2016, Improving STEM learning: What will it take? Australian Council for Educational Research. https://research.acer.edu.au/cgi/viewcontent.cgi?article=1290&context=research_conference

Osborne, S., Paige, K., Hattam, R., Rigney, L. I., & Morrison, A. (2019). Strengthening Australian Aboriginal participation in university STEM programs: A Northern Territory perspective. *Journal of Intercultural Studies*, *40*(1), 49-67. https://doi.org/10.1080/07256868.2018.1552574

Shay, M., Sarra, G., & Lampert, J. (2022). Indigenous education policy, practice and research: Unravelling the tangled web. A*ustralian Educational Researcher, 50*(1), 73–88. https://doi.org/10.1007/s13384-022-00581-w

Trimmer, K., Gower, G., & Lock, G. (2018). Reinventing another Unaipon: Indigenous science leaders for the future. *Australian Journal of Indigenous Education, 47*(2), 216–225. https://doi.org/10.1017/jie.2017.14

Research design

This research aimed to create a data-informed, Indigenous-driven understanding of how to increase and retain Aboriginal and Torres Strait Islander peoples in STEM sectors. The project had four distinct outputs in developing recommendations for improving diversity in STEM as part of the *Pathway to Diversity in STEM Review*. The multimethod approach intentionally allowed for different types of data to emerge to produce new and novel knowledge on how Australia can increase the number of Indigenous Australians taking up education and careers in STEM fields. This research, including the design, data collection, and reporting, was Indigenous led and theoretically informed by Rigney's (1999) three Indigenous research principles: resistance as the emancipatory imperative; political integrity; and privileging the voices of Indigenous peoples.

Study 1: Systematic literature review

Using PRISMA, this review examined what existing research has found about Indigenous participation in STEM. The systematic review asked the central question: What is represented in the literature regarding Indigenous participation in STEM? The review sought to understand what supported Indigenous peoples' engagement in STEM from a strengths-based approach that was inclusive and encompassed Indigenous ways of knowing, being, and doing. This meant that two separate searches were conducted; the first search presented a culturally informed way of engaging with STEM and the second search was formulated to capture general mentions of Indigenous peoples' participation in STEM.

Study 2: Survey

This study employed a community-based online survey design methodology to implement the *Big Mob: STEM It Up* survey. This online survey aimed to provide diverse Indigenous peoples with the opportunity to share their perspectives on STEM, and their interests, aspirations, and perspectives on how inclusive the STEM field is of Indigenous knowledges, peoples, and perspectives.

Prior to the delivery of the online survey for the main study, a draft survey was distributed to team members to provide feedback. This feedback was incorporated into future iterations of the survey design. A small pilot survey was then undertaken with community members. The pilot provided information regarding survey completion time, redundant questions, and clarifying instructions. There were no identified errors or changes to make following the pilot; thus, the survey remained as designed and distributed across Australia.

In total, the final survey comprised 29 questions across two parts (seven demographical questions; 22 questions relating to STEM). There was a mix of multiple-choice questions, five-point Likert Scale items, and open-ended questions for participant responses. To ensure all participants could access the online questions, each item had a digital voice file so the item could be read to participants. Where items required a written text response, participants could use voice-to-text functions on their mobile devices to provide their answer. The survey took approximately 20 minutes to complete.

Survey implementation and recruitment

As the survey aimed to approach a wide range of community members and not necessarily only those who work in STEM, the primary way of approaching participants was through the Indigenous community snowballing method where the information was shared via text message and through existing networks (Woodley & Lockard, 2016). Initially a recruitment text message was created and shared with the Indigenous Chief Investigator's personal, community, and professional networks to connect with Indigenous peoples. The text message had a link to the online survey designed through Qualtrics that provided participants with the information about the project, consent, and the survey itself. It also outlined that participants need to be of Aboriginal and/or Torres Strait Islander descent to participate in the survey. Once completing the survey, participants could share the text message to their personal, community, and professional networks.

Survey analysis

Both quantitative and qualitative analysis methods were employed for the survey data. All survey responses were exported from Qualtrics into a statistical analysis software program (R). Data were cleaned to remove any survey responses that were invalid for the purpose of the study. For example, where a participant had not responded to any items or if there were particular patterns in the qualitative data sets where nonsensical repeated answers were given.

Quantitative analysis: Frequencies, including response count and percentages, were calculated for each scaled item. If required, items were further analysed in line with the demographic data provided in the study. For some items, means scores were calculated.

Qualitative analysis: The qualitative data analysis supports the quantitative analysis to provide a rich and wholistic story centring of the voices of Aboriginal and Torres Strait Islander peoples. All open-ended items were thematically analysed. This included the use of open coding where the researchers examined the initial data to identify similarities and differences, and to establish initial categories/codes (Creswell, 2008). A set of refined codes were developed for each open item and merged back to the relevant datasets. Then axial coding was undertaken to examine the established codes and identify the connectedness between categories. Finally, selective coding was used to examine the interrelationships between the codes to determine a deeper understanding of the research and potential findings that emerged (Creswell, 2008).

Study 3: Podcast

The podcast series talks to diverse Indigenous STEM advocates, practitioners, professionals, and academics about their education and career journeys in STEM. Drawing from a strengths-based approach, the podcast privileges the voices of Indigenous peoples trailblazing in STEM. For this research, the podcasts also served as qualitative interview data. Using yarning (Bassarab & Ng'andu, 2010), the interviews (podcast) aimed to generate stories and perspectives of Indigenous peoples in STEM professions.

Each interview was undertaken by the same researcher and took approximately between 15 minutes to one hour depending on what information the participant shared. All interviews were audio-recorded and then later transcribed for analysis.

As the podcast is publicly available, participants have agreed to be identifiable. Where participants have been interviewed, but have not consented to public podcast release, their information has been deidentified and included in the broader data set. The interview transcripts from the podcasts were coded using NVivo software for the purpose of this report, contributing to our understanding of Indigenous participation in STEM in Australia.

Study 4: International case studies

For the purpose of this research, the STEM international case studies provided a better understanding into the complexities and nuances of practices within the global space. The different case studies examined how countries delineate their policies, manage practices, and address challenges within the field to contribute to the advancement of knowledge in STEM fields. These case studies thus provided an opportunity to apply knowledge across the different case study contexts (New Zealand, Canada, and the United State of America (Alaska)) and facilitate cross-cultural understanding of those issues.

In the international case studies, there were identified criteria that were considered as critical components. These criteria contributed to the selection of countries for the comparative cases. The set criteria for selection and inclusion were as follows:

- The countries selected must be from a colonised context with a distinct Indigenous population.
- There is an established program or policy intervention with an increased participation in a STEM field, highlighting different examples across STEM.
- There are peer-reviewed evaluations or publications on the success of the intervention.
- The chosen program demonstrates sustainability within the intervention design.

References

Bessarab, D., & Ng'andu, B. (2010). Yarning about yarning as a legitimate method in Indigenous research. *International Journal of Critical Indigenous Studies, 3*(1), 37–50. https://doi.org/10.5204/ijcis.v3i1.57

Creswell, J. W. (2008). *Research design: Qualitative, quantitative, and mixed methods approaches* (3rd ed.). Sage Publications.

Rigney, L. I. (1999). Internationalization of an Indigenous anticolonial cultural critique of research methodologies: A guide to Indigenist research methodology and its principles. *Wicazo Sa Review*, *14*(2), 109-121.

Woodley, X. M., & Lockard, M. (2016). Womanism and snowball sampling: Engaging marginalized populations in holistic research. *The Qualitative Report, 21*(2), 321-329. doi: 10.46743/2160-3715/2016.2198

Study 1: Systematic literature review

Aims of the study

This project aimed to understand Aboriginal and Torres Strait Islander peoples' participation in science, technology, engineering, and mathematics (STEM), and determine the nature of this participation. A systematic literature review was undertaken with the central question: What is represented in the literature regarding Indigenous participation in STEM?

Initially it was determined that the search would be undertaken with a focus on Indigenous cultural knowledges that Indigenous peoples may consider to be STEM. This meant that the systematic literature review was starting from a strengths-based approach that was inclusive and encompassed Indigenous ways of knowing, being, and doing from the initial onset when understanding what supported Indigenous peoples' engagement in STEM. This first search presented a culturally informed way of engaging with STEM inclusive of Indigenous knowledges. Following this initial search, a second literature search was undertaken to capture general mentions of Indigenous peoples' participation in STEM.

Methods

This systematic review of empirical research was conducted across five databases: ProQuest, Scopus, Web of Science, PsycInfo, and Informit.

Search 1 was driven by six key research concepts in relation to the research question but with an emphasis on Indigenous cultural knowledges as the central focus. These concepts were: (1) Australian context; (2) cultural background; (3) STEM; (4) Indigenous knowledges; (5) participation; and (6) nature of participation. **Table 3** provides an example of research concepts and related search terms used in Search 1, which searched across abstracts only.

Table 3
Search 1 Concepts and Search Terms for Systematic Review

Concept 1: Australian context		Concept 2: Cultural background		Concept 3: STEM		Concept 4: Indigenous knowledges		Concept 5: Participation		Concept 6: Nature of participation
Australia OR Queensland OR “New South Wales” OR Tasmania OR “South Australia” OR “Australian Capital Territory” OR “Western Australia” OR Victoria OR “Northern Territory”	AND	Indigenous OR Aborigin* OR “Torres Strait*” OR “Indigenous Australia*” OR “Australian Aborigin*” OR “First Nations” OR Blak OR Black	AND	STEM OR Science OR Technology OR Engineering OR Math*	AND	“Indigenous knowledge*” OR “Aboriginal knowledge*” OR “Torres Strait Islander knowledge*” OR “cultural knowledge*” OR “land management” OR “sea management” OR “ranger” OR “bush medicine” OR “kinship systems” OR “caring for Country” OR Country OR Astronomy OR “fire burning” OR “traditional burning” OR “Rock Art” OR “Indigenous ways”	AND	Participat* OR engag* OR involv* OR retention OR retain* OR recruit* OR enrol* OR attrition	AND	education OR career OR industry OR work OR employ*OR tertiary OR universit* OR college OR “professional development”

Search 2 was driven by five key research concepts in relation to the research question. There was an emphasis on mainstream STEM literature from a Western construct of STEM. Therefore, in Search 2, Indigenous knowledges were not the central focus, and the nature of participation was not included in the search to broaden the scope of the results. The concepts were: (1) Australian context; (2) cultural background; (3) STEM; (4) participation; and (5) exclusions. Due to our results in Search 1, it was decided for Search 2 to add an exclusion column to reduce the number of unrelated results, as many publications were focused on health, law, social work, and Indigenous patients or subjects of research rather than active participants in STEM fields. Search 2 also applied an additional measure of a location filter in the databases, due to the large number of results that still included international contexts. **Table 4** provides an example of research concepts and related search terms used in Search 2, which searched across abstracts only.

Table 4
Search 2 Concepts and Search Terms for Systematic Review

Concept 1: Australian context		Concept 2: Cultural background		Concept 3: STEM		Concept 4: Participation		Concept 5: Exclusions
Australia OR Queensland OR “New South Wales” OR Tasmania OR “South Australia” OR “Australian Capital Territory” OR “Western Australia” OR Victoria OR “Northern Territory”	AND	Indigenous OR Aborigin* OR "Torres Strait*" OR “Indigenous Australia*” OR “Australian Aborigin*” "First Nations" OR Blak OR Black	AND	STEM OR Science OR Technology OR Engineer* OR Math*	AND	participat* OR engag* OR involv* OR retention OR retain* OR recruit* OR enrol* OR attrition OR pathway	NOT	health OR “public health” OR nurs* OR patient* OR law OR legal OR “social work” OR justice

Inclusion/exclusion criteria

The publications that were retrieved from Search 1 and Search 2 were then examined and moderated against the inclusion and exclusion criteria developed as part of the protocol for the study. **Table 5** overviews the inclusion and exclusion criteria used.

Table 5
Inclusion and Exclusion Criteria for Search 1 and Search 2

Inclusion criteria	Exclusion criteria
• Peer reviewed (dependent on database) • Literature about/including Indigenous peoples participating in STEM fields (includes traditional practices such as caring for Country, fire burning, bush medicine, etc.) • Publication in English • Full text available • Open publication dates	▪ Literature about non-Indigenous minority groups (e.g., immigrants, refugees) ▪ No mention of Indigenous people participating in STEM fields or Indigenous traditional STEM knowledges ▪ Search terms picked up word ‘stem’ but not the acronym STEM relevant to the search (e.g., stem cell, stem from…) ▪ Publications outside the definition of STEM (e.g., medicine, nursing, community health interventions, justice, law, social sciences) ▪ Publications about culturally inclusive methodologies that are not a direct assessment of active Indigenous participation in STEM

Inclusion criteria	Exclusion criteria
• Australian context (include if international but has Australian participants or case studies)	▪ Publications about technology generally (e.g., use of internet, phones, computers, digital archiving) rather than engagement with technology as a STEM process ▪ Publications about numeracy broadly with no discussion of mathematics specifically ▪ Outside of Australian context (exclude if no Australian participants)

Appraisal process

From the databases, in Search 1, a total of 239 publications were uploaded into Covidence. Once uploaded, a total of 28 duplicates were removed, bringing the search to 211 publications. From this point, 178 publications were deemed irrelevant at the abstract screening phase using the exclusion criteria, which left 33 publications that were taken to full text review. A further 10 publications were excluded during the full text review. The findings report on these 23 publications.

From the databases, in Search 2, a total of 509 publications were uploaded into Covidence. Once uploaded, a total of 122 duplicates were removed, bringing the search to a total of 387 publications. From this point, 282 publications were deemed irrelevant at the abstract screening phase, which left 104 publications that were taken to full text review. A further 24 publications were excluded during the full text review (this included duplicates that were not identified by Covidence as well as publications that were already captured in Search 1). The findings report on these 80 publications.

Results

Authorship

Out of the 23 publications in Search 1 (Indigenous cultural knowledges in STEM), 12 were authored by non-Indigenous peoples, 10 were co-authored by Indigenous Australian and non-Indigenous peoples, and one was authored/co-authored by non-Australian Indigenous peoples (see **Figure 1**). While most authors publishing on Indigenous knowledges in STEM were non-Indigenous, there was still a large proportion of Indigenous Australian co-authorship. There was no sole Indigenous Australian authorship represented in these publications.

Of publications relating to educational experiences, four were authored by non-Indigenous peoples, four were co-authored by Indigenous Australian and non-Indigenous peoples, and one was authored/co-authored by non-Indigenous Australian peoples. Of publications relating to industry, seven were authored by non-Indigenous peoples, while two were co-authored by Indigenous Australian and non-Indigenous peoples. Of publications relating to caring for Country, two were authored by non-Indigenous peoples, while four were co-authored by Indigenous Australian and non-Indigenous peoples.

Of the five publications that included interventions for Indigenous participation in STEM, two were authored by non-Indigenous peoples, two were co-authored by Indigenous Australians and non-Indigenous peoples, and one was authored/co-authored by non-Indigenous Australian peoples.

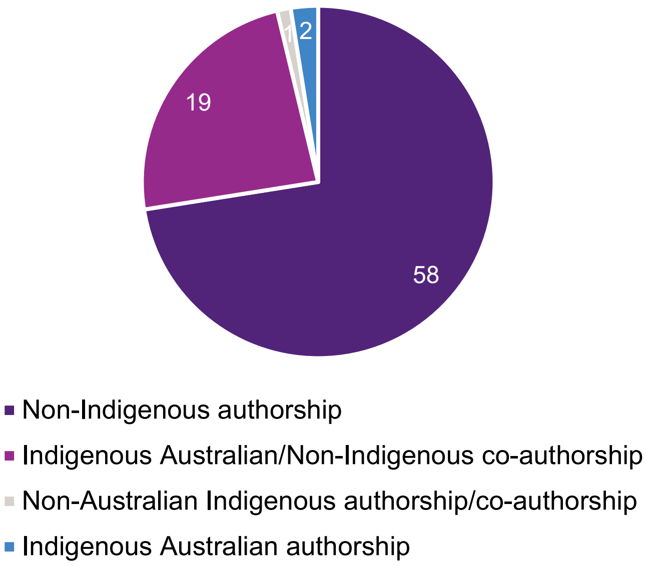
Figure 1
Authorship for Search 1

Out of the 80 publications in Search 2 (Indigenous participation in STEM), 58 were authored by non-Indigenous peoples, 19 were co-authored by Indigenous Australian and non-Indigenous peoples, two were authored by Indigenous Australian peoples, and one was co-authored/authored by non-Australian Indigenous peoples (see **Figure 2**). Most publications in Search 2 were therefore authored by non-Indigenous peoples, with the disparity between non-Indigenous and Indigenous Australian authorship/co-authorship significantly higher than in Search 1. This may reflect the different focus between Search 1 and 2, as Search 2 focused on general Indigenous participation in STEM rather than Indigenous knowledges (which could attract higher Indigenous authorship). Sole Indigenous authorship remained proportionately very low (two of 80).

Of the publications relating to educational experiences, 31 were authored by non-Indigenous peoples, nine were co-authored by Indigenous Australian and non-Indigenous peoples, and two were authored by Indigenous Australians. Of the publications relating to industry, 16 were authored by non-Indigenous peoples, four were co-authored by Indigenous Australian and non-Indigenous peoples, and one was co-authored/authored by non-Australian Indigenous peoples. Of the publications relating to caring for Country, 14 were authored by non-Indigenous peoples and nine were co-authored by Indigenous Australia and non-Indigenous peoples.

Of the 21 publications that included interventions for Indigenous participation in STEM, 17 were authored by non-Indigenous peoples and four were co-authored by Indigenous Australian and non-Indigenous peoples.

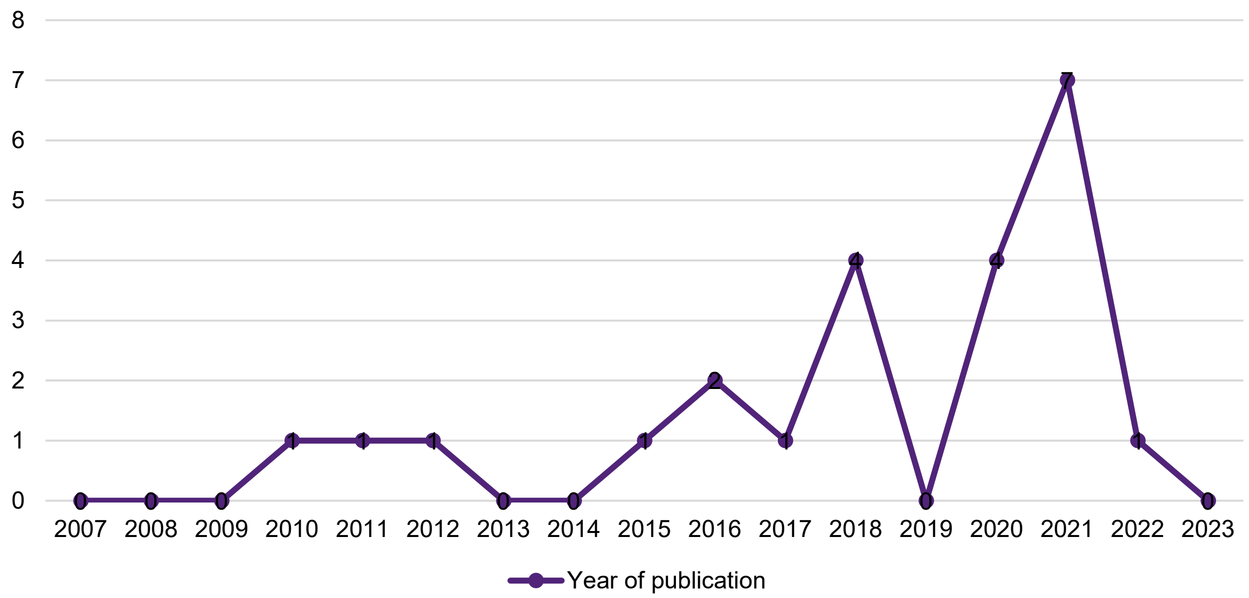
Figure 2
Authorship for Search 2



Years of publication

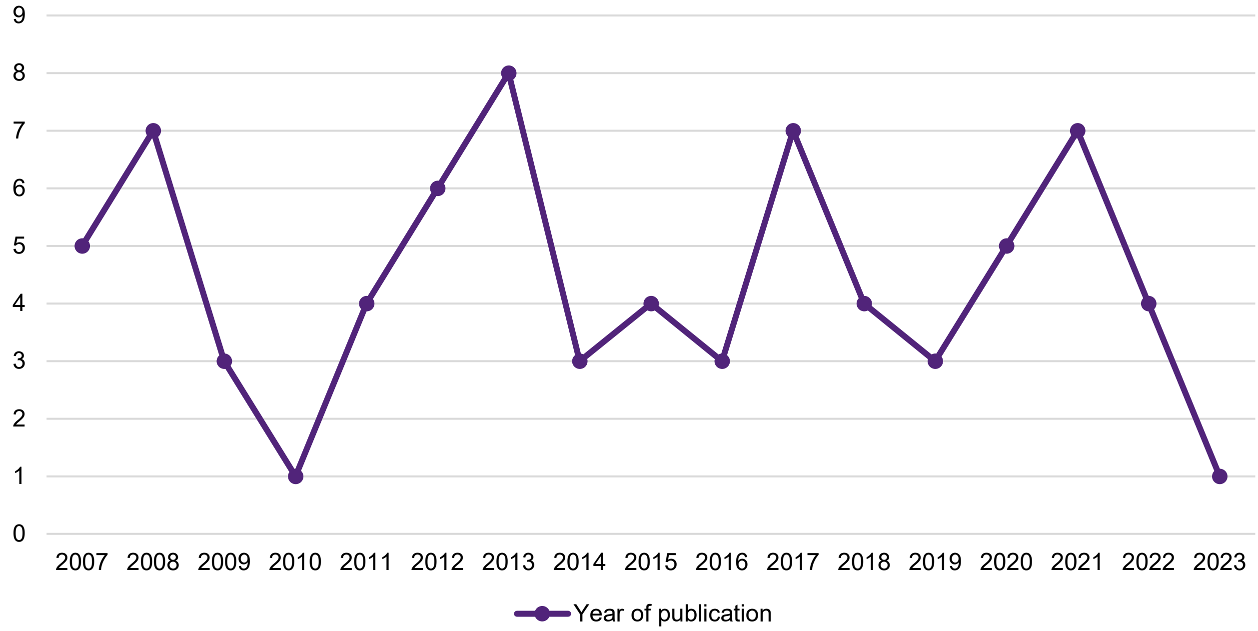
Publications in Search 1 span from 2009 to 2022, with the highest number of publications in 2018 (four) and 2021 (seven) (see **Figure 3**). This suggests Indigenous knowledges in STEM is a more recent and underdeveloped area of research.

Figure 3
Year of Publication for Search 1



Publications in Search 2 span predominantly from 2007 to 2022, with outlier publications in years 1979, 1987, 1990, 1995, and 2000 (see **Figure 4**). Despite a decline in publications in 2010, there is a consistent cyclical publication rate with spikes every four or so years, with the highest number of publications in 2007 (seven), 2013 (eight), 2017 (seven), and 2021 (seven).

Figure 4
Year of Publication for Search 2



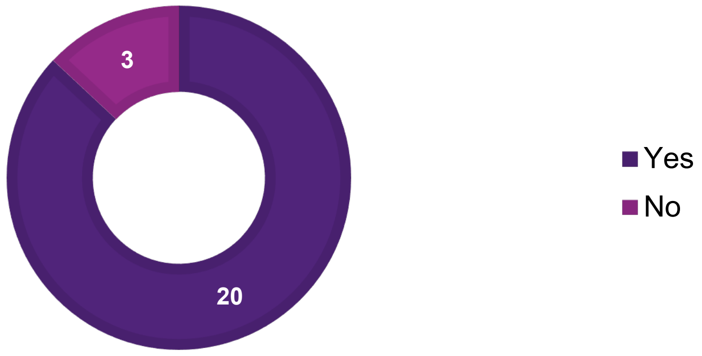
NB: Outliers in Search 2 for years 1979, 1987, 1990, 1995, and 2000.

Indigenous STEM knowledges

The publications in Search 1 revealed most publications (20 of 23) included Indigenous STEM knowledges, with only three publications that did not (see **Figure 5**). Where there was a brief or generalised mention of Indigenous knowledges, the researchers appraised these publications as 'no' and excluded them from the review due to limited mention and/or relationship to STEM. Examples of Indigenous STEM knowledges mentioned were Indigenous and traditional knowledges, astronomy, weather knowledge, medicinal plant knowledges, and animal classification systems.

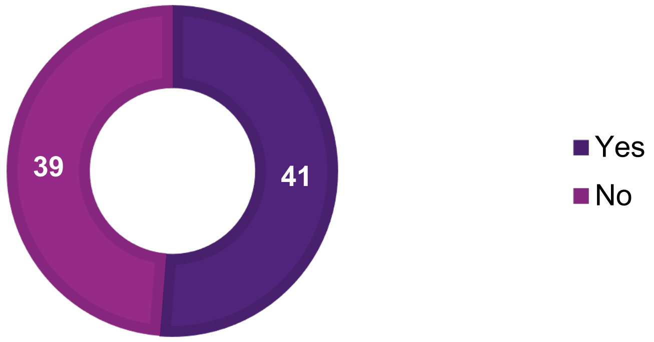
Of the 20 publications that included Indigenous STEM knowledges, over half (11 of 20) of the publications were in the STEM field of science.

Figure 5
Inclusion of Indigenous STEM Knowledges for Search 1



The publications in Search 2 revealed just over half (41) included Indigenous STEM knowledges and just under half (39) that did not (see **Figure 6**). As in Search 1, where there was a brief or generalised mention of Indigenous knowledges, the researchers appraised these publications as 'no' and excluded them from the review due to limited mention or relationship to STEM. Examples of Indigenous STEM knowledges mentioned were traditional ecological knowledges, and land and sea management practices (including fire burning). The search criteria for Search 2 sourced a wider collection of publications in contrast to Search 1.

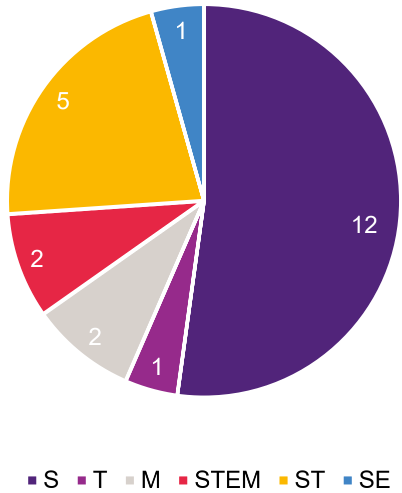
Figure 6
Inclusion of Indigenous STEM Knowledges for Search 2



STEM fields

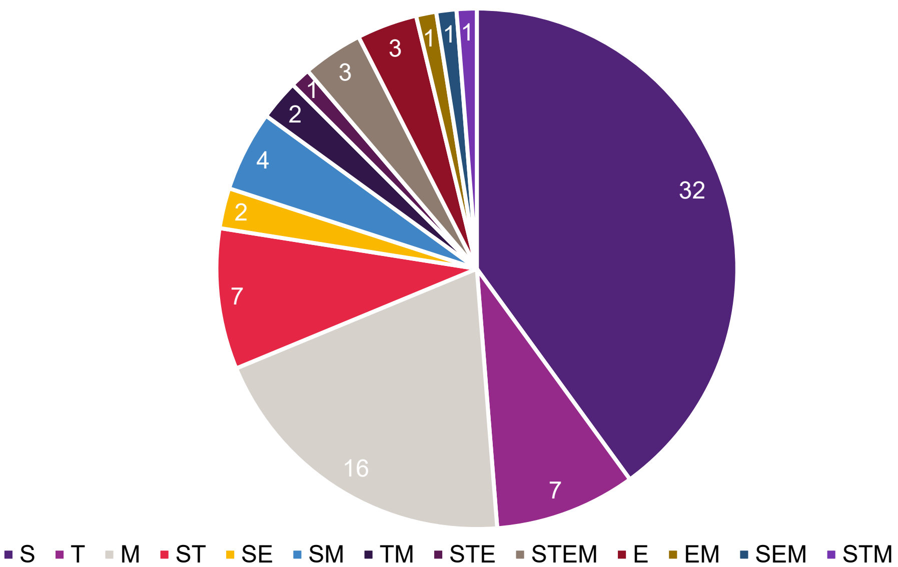
Across Search 1 publications, Indigenous peoples engaged in science more than any other STEM field (see **Figure 7**), with this engagement mostly just in the field of science and based around Indigenous cultural science knowledges. This focus suggests that science is often considered synonymous with STEM, and reflects a greater separation of science, technology, engineering, and mathematics into their own fields in research rather than engaged with as integrated STEM processes. Only two of the 23 publications in Search 1 addressed all aspects of STEM.

Figure 7
STEM Fields for Search 1



There was less segregation of STEM fields and higher instances of representation of two or more STEM fields in individual publications in Search 2 than in Search 1 (see **Figure 8**). For example, there were seven publications on science and technology (ST) and four publications on science and mathematics (SM). However, science remained the dominant field across the literature, with 32 of the 80 publications pertaining to science only. This again suggests that, when examining Indigenous peoples' participation in STEM, science has become synonymous with STEM.

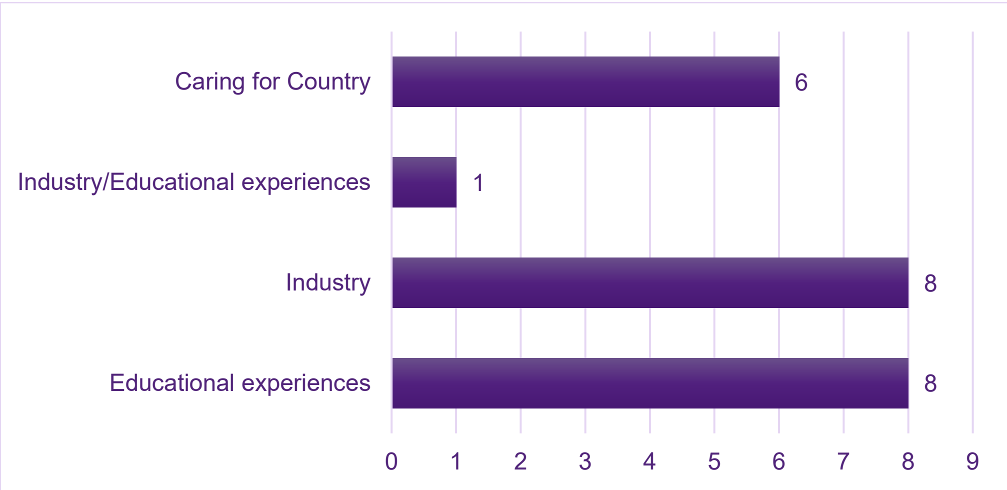
Figure 8
STEM Fields for Search 2



Context of engagement

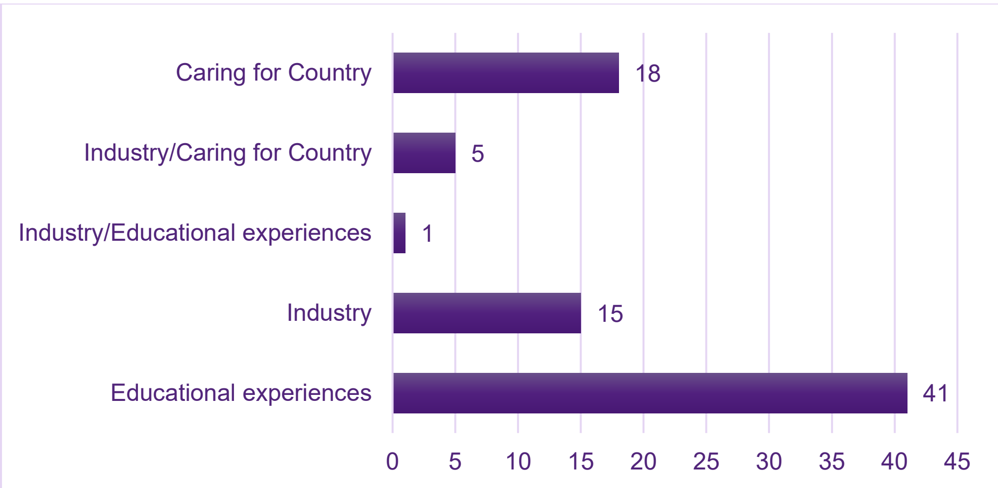
Educational experiences and industry were the highest contexts for Indigenous STEM engagement for publications in Search 1 (see **Figure 9**). Both educational experiences and industry were equally represented by eight publications each (of the total 23 publications). The second highest category was caring for Country (six publications), which also included publications about sustainability and climate change. In contrast, the lowest scoring context of engagement was industry/educational experiences (one publication).

Figure 9
Context of Engagement for Search 1



Most publications in Search 2 focused on the context of educational experiences (41 of the total 80 publications) (see **Figure 10**). The second highest context of engagement was caring for Country, which also encompassed publications on sustainability and climate change. The third highest scoring context of engagement for Search 2 was industry.

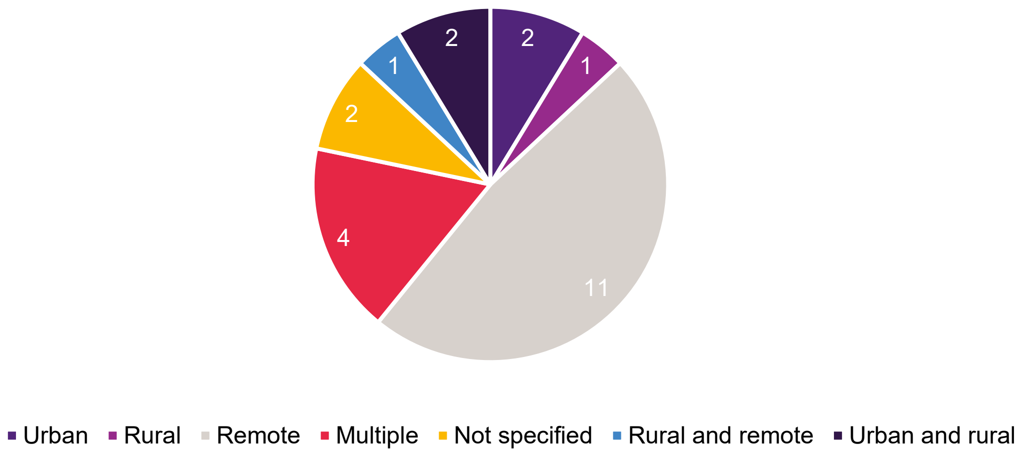
Figure 10
Context of Engagement for Search 2



Location

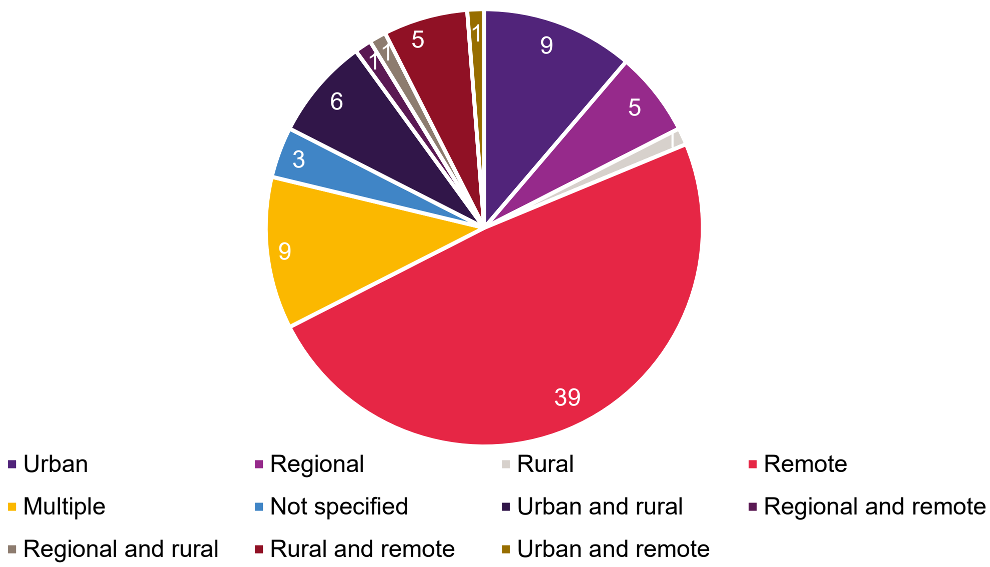
The location of publications in Search 1 revealed that most STEM research is being conducted in remote areas (11 of 23) (see **Figure 11**). However, the remaining publications are a relatively balanced representation across other categories of location.

Figure 11
Location for Search 1



The location of publications in Search 2 again revealed that most STEM research is being conducted predominantly in remote areas, with 39 of the 80 publications focusing on just remote communities (see **Figure 12**). Only nine of the 80 publications were focused on urban areas. Considering recent census data in 2021 that shows that 37.1% of Aboriginal and Torres Strait Islander peoples lived in capital city areas, this is not reflective of the growing urban Indigenous population (Australian Bureau of Statistics, 2022). This may identify an area of need to address issues that impact on or support Indigenous participation in STEM, reflective of various locations.

Figure 12
Location for Search 2



Interventions and evaluations

In this review, there were certain parameters that defined an intervention. It was deemed an intervention if it promoted increased active participation of Indigenous peoples in STEM. For example, a pedagogical approach or educational program that sought to increase active participation in STEM was considered an intervention. Alternatively, if technology was introduced as a way of making current practice more efficient but did not seek to increase participation, this was not considered an intervention.

In Search 1, only five publications had an identified intervention into Indigenous participation in STEM (see **Figure 13**). All five of these publications were about educational experiences (see **Figure 14**) and used qualitative measures to evaluate their interventions (e.g., surveys, interviews, or self-reflection). There was no evidence of sustainability or quantitative measures of long-term student impact.

Figure 13
Interventions for Search 1

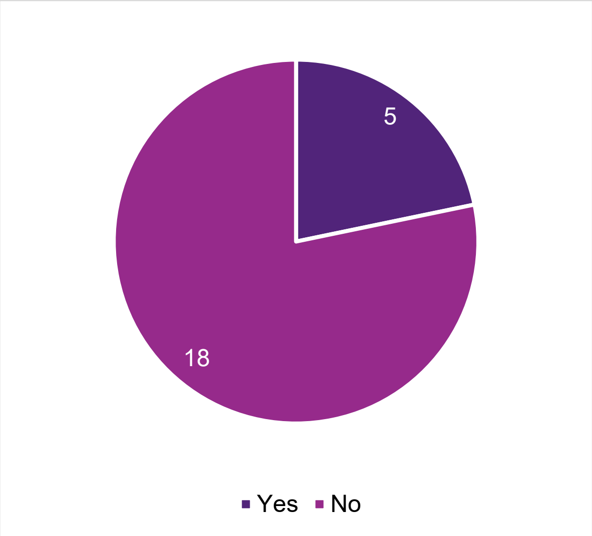
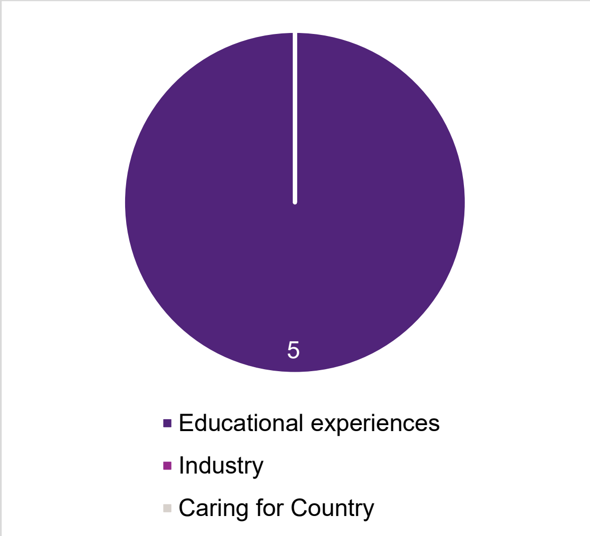


Figure 14
Intervention Context for Search 1



In Search 2, only 23 publications had an identified intervention (see **Figure 15**) and most of these interventions were in the context of educational experiences (18 out of the 23 publications) (see **Figure 16**). Of these 23 publications, 17 were evaluated. From these studies, 14 of these evaluated interventions used qualitative measures to evaluate their interventions, while three had both qualitative and quantitative measures.

Only three publications had evidence of sustainability in their intervention. These included one publication relating to capacity building for continued STEM engagement, one publication relating to an alternative recruitment pathway into a STEM field that is still being used, and one publication discussing a portion of a larger longitudinal study with preliminary indicators of sustainability.

Figure 15
Interventions for Search 2

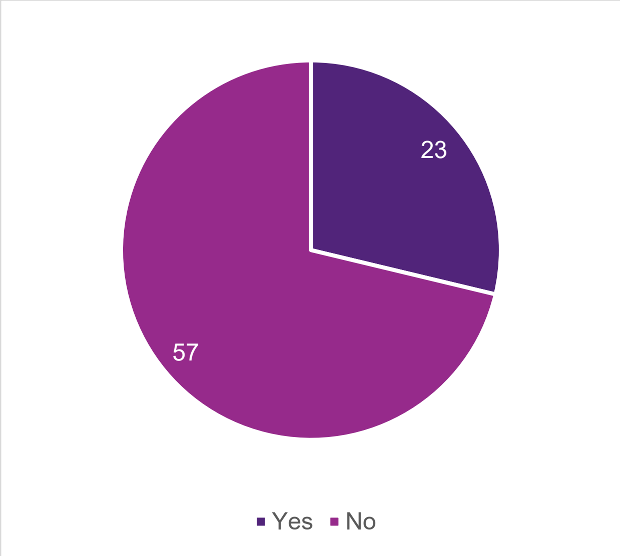
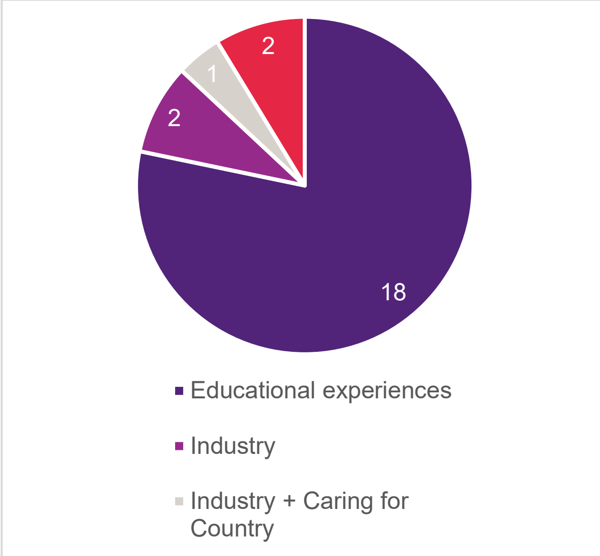


Figure 16
Intervention Context for Search 2



Overall, most publications that described an intervention across Searches 1 and 2 did not include an evaluation of the intervention and, when they did, the evaluation type varied. Many publications relied on self-evaluation where, for example, they used the results section to report on the perceived success of their own intervention. Other publications presented qualitative evaluations based on participant interviews, feedback, or surveys, which often included teacher or researcher observations of student learning. There was overwhelmingly a lack of student voice in the publications for students evaluating their own educational experiences and engagement, which highlights an area that requires attention in future research. There was also minimal evidence of external evaluations.

From this analysis, it can be determined that there is a lack of sustainable and transferable interventions aimed at increasing Indigenous participation in STEM. Future research should ensure that introduced interventions are evidence-driven and that external rigorous evaluations on interventions are conducted to ensure sustainability and transferability.

Strengths and challenges

The following section thematically analyses the qualitative findings across the systematic literature review regarding the strengths and challenges to Indigenous participation in STEM. The sections have been categorised into the following sub-sections to reflect the highest contexts of engagement: educational experiences, industry, and caring for Country (see **Table 6**).

Table 6
Sub-Themes of Systematic Literature Review and Associated Publications

Themes	Sub-themes	Publications
Educational experiences	Community	Ewing, 2014; Howard & Perry, 2007; Jamie, 2021; Robertson et al., 2020; Ruddell, 2021; Siemon, 2009; Thornton et al., 2011.
	ICT for cultural purposes	Darcy & Auld, 2008; Hardy et al., 2016b; Kutay, 2007; Kutay et al., 2010; Singleton et al., 2009; Vaarzon-Morel & Kelly, 2019; Woodley et al., 2014.
	Pedagogy	Armour et al., 2016; Buckskin et al., 2018; Donovan, 2018; Ewing, 2011; Howard & Perry, 2007; Makuwira, 2008; Matthews, 2012; McConney et al., 2011; Rioux & Smith, 2019; Rioux et al., 2018; Sammel & Whatman, 2018; Singleton et al., 2009; Thornton et al., 2011; Treagust et al., 1987; Warren & Miller, 2013; Warren et al., 2007; Warren et al., 2008; Wilson & Alloway, 2013; Yeung et al., 2013.
	Indigenous educators and students as cultural assets	Appanna, 2011; Armour et al., 2016; Grootenboer & Sullivan, 2013; Humphreys, 1995; Matthews, 2012; Rioux et al., 2018; Thornton et al., 2011; Warren & Miller, 2013; Woods-McConney et al., 2013.
	Valuing Indigenous knowledges	Boisselle & McLaughlin, 2021; Boon, 2012; Buckskin et al, 2018; Ewing, 2014; Matthews, 2012; Michie et al., 2018; Rigney et al., 2020; Rioux & Smith, 2019; Rioux et al., 2018; Rioux et al., 2021; Sammell & Whatman, 2018.
	Factors that impact student learning experiences	Aldous et al., 2008; Appanna, 2011; Armour et al., 2016; Boon, 2012; Buckskin et al., 2018; Cooper & Berry, 2020; De Lemos, 1979; Ewing, 2011; Ewing, 2014; Ewing, 2017; Fraser et al., 2021; Grootenboer & Sullivan, 2013; Howlett et al., 2008; Humphreys, 1995; Matthews, 2012; McInerney, 1990; Michie et al., 2018; Papic et al., 2015; Rigney et al., 2020; Rioux & Smith, 2019; Rioux et al., 2021; Ruddell, 2021; Siemon, 2009; Thwaite, 2014; Trimmer et al., 2018; Warren & Miller, 2013; Warren et al., 2008; Warren et al., 2012; Woods-McConney et al., 2013; Yeung et al., 2013.
	Recruitment and retention	Buckskin et al., 2018; Goldfinch et al., 2017; Trimmer et al., 2018.
Industry	Valuing of Indigenous knowledges	Carter & Hill, 2007; Crough, 2015; Fisher et al., 2021; Jellinek et al., 2021; McKemey et al., 2020; Weir, 2021.

Themes	Sub-themes	Publications
	Collaboration and co-design	Bohnet et al., 2013; Cullen-Unsworth et al., 2012; Davies & Holcombe, 2009; Fache & Moizo, 2015; Fisher et al., 2021; Grey-Gardner, 2008; Hardy et al., 2016a; Hemming et al., 2017; Hof et al., 2017; Jellinek et al., 2021; Jennings, 2021; Koenig, 2007; Reed et al., 2021; Russell et al., 2021; Verschurren, 2017; Weir, 2021.
	Capacity building and resourcing	Carter & Hill, 2007; Ens, 2012; Hardy et al., 2016b; Hayashi et al, 2021; Kutay, 2021; Niesche, 2023; Pearson & Daff, 2011; Pearson & Daff, 2012; Phillips, 2017; Woodley et al., 2013; Woodley et al., 2014.
Caring for Country	Indigenous knowledges	Ens et al., 2015; Ens et al., 2016; Marshall, 2020; Milgin et al., 2020; Renowden et al., 2022; Russell & Ens, 2020; Russell et al., 2021; Smith et al., 2018; Stefanelli et al., 2017; Wergin, 2018; Wilcock, 2013; Wilson et al, 2010; Wood et al., 2017.
	Respect and value	Cooke, 1999; Currell et al., 2022; Frantzeskaki et al., 2022; Lyons & Barber, 2021; Ockwell, 2008; Russell & Ens, 2020; Verschuuren, 2017; Wergin, 2018; Wilcock, 2013.
	Governance and decision-making	Carmichael at al., 2020; Ens et al., 2016; Grafton et al., 2020; Jackson & Douglas, 2015; Lilleyman et al., 2022; Lyons & Barber, 2021; Marshall, 2020; Thomassin, 2019.
	Capacity building for the benefit of community	Jackson & Douglas, 2015.
	Engagement and collaboration	Carmichael et al., 2020; Currell et al., 2022; Ens & Turpin, 2022; Hof et al., 2017; Hoverman & Ayre, 2012; Jackson & Douglas, 2015; Marshall, 2020; Ockwell, 2008; Pearson & Daff, 2011; Robinson et al., 2016; Russell et al., 2021; Stefanelli et al., 2017; Thomassin, 2019.

Educational experiences

When investigating what the literature says about Indigenous participation in STEM, the largest number of publications were about educational experiences. These covered school, university, and community education settings; educational programs; pedagogy; and student learning strategies.

Community

When considering the role of parents and Elders in the education of Indigenous young people, it appears that genuine community partnerships with reciprocal benefits improves and promotes: engagement for Indigenous students; authentic knowledge production; teaching and learning outcomes; and community cohesion (Robertson et al., 2020; Ruddell, 2021; Siemon, 2009). Strong connections and collaboration with local community, alongside parents, students, educators, and schools, foster positive interest and engagement (Howard & Perry, 2007). This collaboration is particularly beneficial if it draws on a community's "ways of knowing, practices, and language to provide children with meaningful interactions in their communities" and offers opportunities for community to work alongside Western scientists and practitioners (Ewing, 2014, p. 3; Jamie, 2021). The strengths of community engagement were evidenced throughout the review as a way to foster high expectations. These interactions allow Indigenous teachers and students to meet their communal responsibilities and obligations while learning and connecting to how STEM has real-life application (Thornton et al., 2011). What still appears to be a challenge for some is creating these partnerships, engaging community in learning activities, and developing markers of student capacity and success that are informed and culturally inclusive (Howard & Perry, 2007).

ICT for cultural purposes

Within the educational experiences body of evidence, it was found that technology was predominantly being used for cultural purposes, such as to support cultural and language learning through the use of information and communication technology (ICT) (Darcy & Auld, 2008; Kutay et al., 2010). It was evident in many research projects that there was a need to increase the use of ICT to meet identified needs of community for community benefit (Singleton et al., 2009). Many publications, though, documented the challenges impacting Indigenous participation in ICT (Kutay, 2007). These included: institutional barriers in resources and time constraints in universities (Hardy et al., 2016b); adequate resources and training to engage with ICTs in the community (Woodley et al., 2014); access to ICTs impacted by socio-economic status and lack of infrastructure in remote areas (e.g., Internet and mobile) (Darcy & Auld, 2008; Singleton et al., 2009); access to technology and digital skills; negotiating respectful processes and relationships with Elders; digitised knowledges being misused by other parties (Vaarzon-Morel & Kelly, 2019); and language barriers for English as an Additional Language and/or Dialect (EAL/D) language speakers (Darcy & Auld, 2008).

Pedagogy

When considering the way teachers teach STEM, it has been evidenced that culturally responsive pedagogies engage Indigenous learners (Donovan, 2018; Treagust et al., 1987). An example of a culturally responsive pedagogy that was evidenced as highly successful throughout the review was Both Ways teaching, as it incorporates place-based learning, has real life application to Country, and increases participation (Howard & Perry, 2007; Rioux & Smith, 2019; Rioux et al., 2018). Other successful techniques included: connecting pedagogy to Indigenous knowledge systems to emphasise how learning is relational and connected to all things (Sammel & Whatman, 2018); having high expectations of learners (Yeung et al., 2013); using hands-on materials that support diversity of learning styles (Warren & Miller, 2013); employing strategies for instruction (talking less) that supports Indigenous EAL/D learners (Rioux et al., 2018); and offering flexible learning approaches that support non-traditional approaches to schooling (Singleton et al., 2009; Wilson &

Alloway, 2013). Alternatively, the evidence across this review suggested that teachers were inhibiting Indigenous participation in STEM when their pedagogy: did not recognise diverse ways of knowing and were not culturally affirming (Wilson & Alloway, 2013); was framed by low expectations (Thornton et al., 2011); lacked real-world context and considered learners as passive rather than active (Makuwira, 2008); and relied on Direct Instruction (Ewing, 2011).

It has also been identified across the literature that there are challenges for teachers with regards to supporting Indigenous learners in STEM including: identifying linguistically relevant examples for teaching mathematics using culturally relevant pedagogies (with culturally relevant communication and hands-on activities) (Warren et al., 2008); and delivering content in a culturally sensitive manner that strengthens Indigenous culture whilst simultaneously engaging with Western mathematics (Warren & Miller, 2013). Moving forward to support Indigenous STEM learners through pedagogy, the challenges identified in the review suggests teachers must be aware of: how their pedagogical practice and implementation of the curriculum impacts student performance (McConney et al., 2011); the difference in the pedagogy required to teach STEM subjects and the pedagogies that are required to engage Indigenous students (e.g., how to support a student's cultural identity while they study a STEM degree) (Buckskin et al., 2018); and their cultural capabilities (Armour et al., 2016).

Indigenous educators and students as cultural assets

When considering the way Indigenous educators and students are valued in STEM education, the review overwhelmingly suggested that Indigenous participation improves when Indigenous peoples are considered and respected as cultural assets (Appanna, 2011; Humphreys, 1995; Rioux et al., 2018). If Indigenous staff are treated as knowledge holders in the development of resources, and implementation of curriculum, a culturally safe space for learners can be promoted (Armour et al., 2016; Rioux et al., 2018). It is also essential for non-Indigenous teachers to have high expectations of Indigenous staff (Thornton et al., 2011). If this does not occur, Indigenous staff will be positioned to lack agency and control over Indigenous student learning, negatively impacting STEM participation (Armour et al., 2016). For students, positive engagement can be facilitated by building on existing student knowledge, skills, attitudes, dispositions, beliefs, and prior learning experiences, including their cultural knowledge and assets (Grootenboer & Sullivan, 2013; Woods-McConney et al., 2013). Ultimately, when both Indigenous staff and students are valued as cultural assets, holistic and cultural approaches to education can occur that embrace culture, oral language, and knowledges in the classroom that connect with local Indigenous community (Matthews, 2012; Warren & Miller, 2013).

Valuing Indigenous knowledges

In the educational experiences literature, it became evident that whether or not Indigenous knowledges were valued or legitimised in the curriculum impacted Indigenous students' engagement with STEM. Some literature indicated that most teaching approaches in science illustrate a common pattern where the inclusion of Indigenous knowledge systems is still based on an assimilatory agenda. Ultimately, teachers could serve hegemonic ideas, due to their conditioning to legitimise Western science knowledge in their science education classrooms (Sammell & Whatman, 2018, p. 45), and, as a result, Indigenous knowledges are positioned as "inferior" to Western knowledges (Ewing, 2014). If schools and universities do not readily acknowledge or incorporate Indigenous knowledges in STEM, this continues to devalue Indigenous knowledges in science thinking and pedagogies (Boisselle & McLaughlin, 202; Michie et al., 2018), which causes a disconnect for many Indigenous students (Boon, 2012; Buckskin et al, 2018). Connected to this, the body of evidence in educational experiences highlights that, for Indigenous peoples, "knowledge is holistic and unfragmented within Indigenous thought systems". This means that the fragmentation of 'science' or 'mathematics' in Western terms (Boisselle &

McLaughlin, 2021, p. 132) may not relate to Indigenous learners due to the imposition of Western colonial language, views, content, educative frameworks, and curriculum that lacks context and connection to place-based knowledge (Rioux et al., 2018; Rioux & Smith, 2019). As a way to begin to address the disconnect, there is evidence suggesting that, if Indigenous knowledges are taught alongside Western knowledges, moving away from prescribed pedagogies towards culturally responsive pedagogies (Rigney et al., 2020), the transferability of these skills become evident and supports Indigenous learners (Rioux et al., 2021).

Factors that impact student learning experiences

Across Indigenous education research generally, there are several identifiable factors that are said to impact Indigenous students' learning, such as socio-economic barriers and school attendance (Humphreys, 1995; McInnerney, 1990). In STEM specifically, factors impacting participation include institutional barriers (e.g., constructs of race) and relevance of school curriculum (Appanna, 2011), which encompasses standardised measures of achievement that do not consider learning styles, worldviews of learners, and EAL/D learners (Grootenboer & Sullivan, 2013; Matthews, 2012; Siemon, 2009). For example, Indigenous students may be unfamiliar with Western mathematical constructs (Ewing, 2011; Warren et al., 2008), due to differences between community/daily life mathematics and school mathematics (Ewing, 2014). Additionally, findings from the review indicated that non-Indigenous teachers with negative perceptions, who are often ill-equipped to teach Indigenous learners, also negatively impact participation and the learning experience of students (Warren & Miller, 2013).

It is suggested that, for remote Indigenous learners, Western science may differ significantly from everyday life and experiences (Boon, 2012), especially when compared to urban students' knowledge (Michie et al., 2018). As such, for Indigenous learners from remote communities, additional barriers were identified, including: inexperience of teachers; lack of curriculum knowledge and appropriate support structures; isolation; limited employment opportunities; and lack of resources (Warren & Miller, 2013, p. 166). When considering how these factors impact students' transition to higher education, evidence suggests low STEM-related literacies for Indigenous school students (e.g., mathematics) can impede progression to STEM disciplines at university. Similarly, literacy rates in general need to be supported as students may have aptitude for STEM but low literacy rates may create issues with successfully completing assessment (Buckskin et al., 2018). Alternatively, identified support factors that promoted Indigenous participation include; educational experiences that foster cultural safety, identity, and belonging; finance, family, and community support; and engagement of Elders (Trimmer et al., 2018).

Teachers play a significant role in influencing Indigenous participation in STEM; this influence can be positive or negative and this is dependent on the cultural capabilities of teachers (Armour et al., 2016) and their level of experience (Warren et al., 2012). The body of evidence comments on how the lack of teacher preparation in culturally responsive pedagogies for diverse student populations impacts participation in STEM (Rigney et al., 2020; Ruddell, 2021). Further challenges for teachers include their own competency in supporting and teaching EAL/D learners (Rioux & Smith, 2019; Thwaite, 2014). These challenges accumulate in high teacher turnover in remote communities (Siemon, 2009), negatively impacting Indigenous students' experiences of STEM.

Across the literature pertaining to educational experiences, something that was commonly recognised as a barrier to Indigenous peoples' participation in STEM was negative self-perceptions of ability and capability of STEM skills. This is possibly a result of assessing Indigenous Australians' science literacy from a Western scientific framework (Boon, 2012) and Indigeneity status being used as a predictor for participation in science subjects (Cooper & Berry, 2020, p. 151). From this, if science literacy is deemed to be low, gap rhetoric and negative positioning is established, which can be exacerbated when paired with a lack of culturally responsive curriculum

(Rioux et al., 2021). This impacts students' and communities' self-perceptions of Aboriginal and Torres Strait Islander peoples' capability in mathematics and science, potentially further impacting students' engagement and participation (Fraser et al., 2021; Howlett et al., 2008; Woods-McConney et al., 2013). Another factor that the body of evidence argued impacted Indigenous peoples' self-perception of STEM ability was rurality (Yeung et al., 2013). This impacted not only the students, but families too as remote Indigenous parents have reported less confidence in assisting their children with science homework in comparison to non-Indigenous parents (Boon, 2012).

Recruitment and retention

An evident area for further research is the recruitment and retention of Indigenous peoples in STEM within higher education. Publications suggest there are little to no consistent or university-wide approaches to Indigenous STEM recruitment, which also impacts data collection on interventions and programs as implemented activities are siloed (Buckskin et al., 2018). Challenges identified in the literature that were identified as impacting the recruitment and retention of Indigenous students in STEM in higher education included: financial stress; long distance between university and home; racism and prejudice towards Indigenous people; perceived low level of readiness of Indigenous students; insufficient academic support; poor health and disability; low level of Indigenous content; and absence of Indigenous lecturers (Trimmer et al., 2018). These align with broader challenges that have been identified for Indigenous cohorts, including: being first-in-family to attend university; a lack of role modelling; and the broader impacts of colonisation (Goldfinch et al., 2017). One suggested way to initially address recruitment issues would be to explain to prospective Indigenous students how STEM-related qualifications might link back to the needs of their communities (Buckskin et al., 2018).

Industry

After educational experiences, Indigenous participation in STEM industry was the second highest context of engagement across the literature (30 out of 103 publications). The publications in this category overwhelmingly focused on science and the environmental management industry – namely, land, water, sea, and natural resources management. While Indigenous engagement with information technology was often discussed in relation to environmental management or cultural heritage management, no publications focused on Indigenous participation in the information technology industry itself. Four publications related to the engineering industry, with two specifically focused on Indigenous recruitment interventions in the mining industry (Pearson & Daff, 2011, 2012). No publications focused on Indigenous participation in the mathematics industry.

When categorising the literature, we identified industry publications as those that involved engagement between Indigenous peoples and government or industry stakeholders for the purposes of policy, research, or management practices (most often environmental). Publications which identified Indigenous peoples working as Rangers or with Ranger programs as an occupation were also categorised under industry. Publications that focused on teachers or teaching as a profession (e.g., mathematics teaching) were excluded from this category and have been discussed under educational experiences.

Value of Indigenous knowledges in industry

Across the literature, traditional Indigenous ecological knowledges and Ranger practices were valued and considered beneficial to existing government or industry environmental management strategies. A particular focus of many industry publications was on fire burning practices and the demonstrated cross-cultural benefits of incorporating traditional Indigenous knowledges and

Ranger knowledges in current Western-based government fire management models (Fisher et al., 2021; Jellinek et al., 2021; McKemey et al., 2020). For example, local Indigenous ecological knowledges and seasonal calendars contained valuable, alternative information that resulted in a more comprehensive understanding of fire management and better environmental outcomes, including reduction in burn areas and greenhouse gas emissions (McKemey et al., 2020). When engaging with Indigenous knowledges, it is crucial that policy and legislative support is established to ensure that intellectual ownership of Indigenous knowledges remains with traditional knowledge custodians and that these knowledges are protected from misappropriation by non-Indigenous parties. This is evidenced by a case study on Indigenous community-based fisheries management where, despite intellectual property arrangements, Indigenous ecological knowledges were disseminated wider than the intended stakeholders, resulting in exploitation by commercial fishers (Carter & Hill, 2007).

While Indigenous knowledges in industry were discussed from a positive, strengths-based lens, authors did acknowledge how the history of colonisation and ongoing institutional barriers have continued to dismiss, silence, or misunderstand the value and application of Indigenous knowledges in environmental industry fields (Crough, 2015; Weir, 2021).

Collaboration and co-design

The literature on industry contexts demonstrated that the involvement of Indigenous stakeholders in the co-design of projects and research initiatives in environmental management has positive outcomes for people and the environment (Weir, 2021). When Indigenous peoples were considered as equal partners and involved across all levels of project design, development, and implementation, the result was a greater co-production of cross-cultural ecological knowledges that were better suited to sustainably manage local problems (Cullen-Unsworth et al., 2012; Fisher et al., 2021; Hof et al., 2017). The literature also highlighted that it is not enough that projects are designed *with* community; they must also be designed *for* community (Hardy et al., 2016a). Projects that were designed with Indigenous communities to meet Indigenous community needs and involved Indigenous stakeholders (e.g., Rangers, Elders) across all areas of decision-making and governance resulted in the following benefits: training and employment opportunities for Indigenous community members; research outputs and resources that stayed with communities for greater agency self-managing traditional lands and waters after projects had ended; and better and long-term partnerships between Indigenous communities and external government agencies for environmental management purposes (Hemming et al., 2017; Hof et al., 2017; Verschurren, 2017).

The literature identified several ways to support Indigenous collaboration and engagement in science-related projects and research initiatives, which included in-built opportunities for capacity building; flexible project timeframes that account for Indigenous cultural obligations; and the provision of clear, accessible information and communication networks for Indigenous communities (Cullen-Unsworth et al., 2012; Hemming et al., 2017; Jellinek et al., 2021). Many authors did acknowledge ongoing institutional and power barriers impacting engagement, which included the prioritisation of Western views in research (especially by Western funding bodies); historic exclusion of Indigenous knowledges and peoples from government and scientific investigations; historic exclusion of remote Indigenous communities in policy discussions (which are often made in urban settings); historic exclusion from roles in decision-making, policy and governance; and limited roles when Indigenous peoples were included (e.g., Rangers could collect but not analyse data) (Davies & Holcombe, 2009; Fache & Moizo, 2015; Russell et al., 2021).

There was a lack of case studies on Indigenous collaboration and involvement in engineering, mathematics, and information technology industries. In relation to the science industry, there was a lack of research into Indigenous involvement in the co-development of policy and legislation with government bodies and stakeholders. This is of particular importance given the ongoing impact that contemporary Australian laws have on Indigenous peoples' ability to engage in traditional land and sea management, and in environmental projects and initiatives with government and industry stakeholders (Koenig, 2007; Verschurren, 2017). These are areas that require further research.

Capacity building and resourcing

The literature highlighted that efforts to increase Indigenous participation in STEM industry must include opportunities for individual and community capacity building, as well as adequate resourcing to support this. Engagement with ICTs by Indigenous Rangers and communities was consistently identified as important for supporting environmental management and cultural heritage industries, and subsequently for fostering self-determination and building skills for Indigenous stakeholders to independently care for their own lands, waters, and cultures. Indigenous Rangers and communities that engage with GPS (Global Positioning System), mapping and tracking software, and drone equipment develop a complementary technological skillset that can enhance traditional environmental management practices, particularly with respect to land and fire management (e.g., aerial tracking of fires) (Ens, 2012; Woodley et al., 2014). In cultural heritage management organisations, Indigenous peoples and communities have engaged with information systems to build online databases and records for the preservation of valuable cultural knowledges and languages (Hardy et al., 2016b; Kutay, 2021). To fully engage with ICTs in these capacities requires training, access to and funding for ICT equipment, and adequate infrastructure (i.e., Internet) for Indigenous peoples and communities across Australia, which many authors noted is currently lacking (Kutay, 2021; Woodley et al., 2013). Additional barriers that may deter engagement with ICTs in these ways include information systems being designed in Western frameworks and languages, concerns about the security and data sovereignty of sacred knowledges online, and transferring Indigenous knowledges that are time and place bound into timeless online environments (Carter & Hill, 2007; Hayashi et al, 2021; Kutay, 2021).

Overall, there is a lack of literature focusing on recruitment of Indigenous peoples into STEM industries. Two of the publications reviewed focused on an alternative recruitment pathway for increasing Indigenous peoples' employment and retainment in the mining industry (Pearson & Daff, 2011, 2012). The strengths of this pathway included program flexibility, recognising cultural responsibilities of Indigenous workers, and alternative recruitment assessments that are not based on national or standardised testings and which account for Indigenous languages and oral cultural traditions (Pearson & Daff, 2011, 2012). While such pathways may have wider application for recruitment in other STEM industries, further research is required into recruitment strategies that recognise Indigenous capabilities, support capacity-building, and foster flexible, culturally safe working environments.

Caring for Country

Caring for Country was the third largest category (29 out of 103 publications) after industry, and included literature that encompassed environmental management, land and sea management, sustainability, and climate change. The literature review identified a consistent body of evidence describing the strengths of Indigenous participation in STEM in environmental management and caring for Country practices, which were most evident in the areas of Indigenous knowledges, community participation in governance and decision-making, and capacity building for the benefit of community.

Indigenous knowledges

A critical component identified in the literature was valuing the contribution of Indigenous knowledges and their consideration of equal value and importance alongside Western knowledges in STEM fields. The recognition of Indigenous knowledges, and their contribution to environmental management and sustainable practice, was essential in caring for Country.

The literature cited the value of Indigenous knowledges and its importance alongside Western knowledges. It also acknowledged the challenges, and the need, for equal value of Indigenous knowledges and recognition in caring for Country. There was a body of evidence that recognised holistic relational values of Indigenous knowledges in environmental management (Russell & Ens, 2020), and the recognition of relational thinking for sustainability research and practice (Milgin et al., 2020). Evidence cited the use of both Indigenous and non-Indigenous knowledges (Smith et al., 2018) in caring for Country and sustainable practice using holistic approaches to conservation management (Renowden et al., 2022). The literature indicated that Indigenous knowledges and cultures enrich and contribute to environmental knowledge and decision-making, and can inform ecosystem management (Ens et al., 2015; Renowden et al., 2022; Wilcock, 2013).

Intergenerational knowledges from Indigenous Ecological Knowledge (IEK) were identified in the review as important for understanding changes to the environment over time, including pre- and post-colonial events (Russell et al., 2021). One example was that Indigenous participation increases biodiversity knowledge of species alongside preserving threatened traditional knowledges (Ens et al., 2016). While the strengths of Indigenous knowledges were recognised and valued as of equal importance to Western knowledges, the literature acknowledged the challenges in recognising Indigenous knowledges. This included the historic lack of Indigenous knowledges considered in Western ecological management and in evaluating sustainable environmental management practice (Milgin et al., 2020; Russell et al., 2021; Stefanelli et al., 2017). Evidence suggested Western conservation strategies are prioritised over Indigenous knowledges including Indigenous protocols in caring for and maintaining Country and environmental conservation (Ens et al., 2015; Marshall, 2020). Evidence indicated Indigenous knowledges must be considered in research design (Wergin, 2018).

Respect and value

Although the evidence indicated the value of Indigenous knowledges as essential to conservation (Ockwell, 2008), authors noted concerns over the misappropriation and misuse of Indigenous ecological knowledges (Wergin, 2018). Evidence consistently cited that institutional barriers of historical marginalisation and Indigenous participation impact the respect for and value of Indigenous knowledges in environmental management. The barriers included historical colonial relations of power, the socioeconomic status of Indigenous peoples, and the Eurocentric nature of environmental decision-making (Wilcock, 2013). Institutional barriers and the critical points raised below emphasise the need to learn from Indigenous ways of knowing, being, and doing.

Critical points included the use of Indigenous knowledges valued through principles of caring for Country in policy and practice (Frantzeskaki et al., 2022), and in development and planning processes (Lyons & Barber, 2021). Authors acknowledged that “the lessons shared from Traditional Owners for many years have not been taken seriously nor adopted into best practice methods of governance and engagement” (Currell et al., 2022, p. 920). Evidence indicated the historical marginalisation of Indigenous peoples has led to barriers in traditional land and fire management (Cooke, 1999), in addition to challenges resulting from colonisation (e.g., mitigating the introduction and growth of exotic grasses in land management) (Cooke, 1999). Verschuuren (2017) provided evidence of non-Indigenous impacts affecting Indigenous land and sea management, such as destruction of coral and marine life.

Authors acknowledged the challenge of incorporating relational values of Indigenous knowledges in natural resource management. Eurocentric reductionist worldviews of ecosystem assessment “did not correspond with the reciprocal human-Country relationship from an Australian Indigenous context” (Russell & Ens, 2020, p. 9). For example, evidence suggested challenging the current

Ecosystem Services (ES) paradigm that has become a cornerstone of environmental conservation and pushing the narrative in a more relational direction. This would allow for a deeper understanding of Indigenous connectivity and responsibilities that enable respect and value of participation of Indigenous knowledges in natural resource management (Russell & Ens, 2020). Additionally, evidence cited the inconsistencies between customary laws and contemporary Australian law over sea rights and management, indicating "the challenge for modern-day conservation is to be able to effectively transpose such intimate cultural and spiritual relations into ecosystem management" (Verschuuren, 2017, p.106).

Governance and decision-making

A key component identified in the literature was the recognition of Indigenous community involvement in governance and decision-making processes. The recognition of Indigenous peoples as sovereign partners in governance, policy development, and research in STEM is essential for increased participation. From the review it was evident the strengths of Indigenous governance (Thomassin, 2019) and co-responsibility in caring for Country (Lyons & Barber, 2021). The benefit of collaboration leads to empowerment in the co-production of knowledge and research together (Lilleyman et al., 2022). One example of the strength of Indigenous governance was cited in the Torres Strait, where Torres Strait Islanders have developed a range of political strategies to achieve their goals of autonomy and land-sea ownership to manage traditional lands and seas (Thomassin, 2019). Despite the strengths of Indigenous governance and decision-making, challenges of Indigenous community participation were identified due to the difference between Indigenous and non-Indigenous governance structures.

Governance was deemed by some to be the responsibility of stakeholders in non-Indigenous structures employed through government agencies, which negatively impacted Indigenous peoples (Carmichael et al., 2020). This conceptualisation of governance clashed with the Indigenous definition of governance (Marshall, 2020) due to the differences in Western models of governance, economic and policy motives, and the impact these have on Indigenous peoples in environmental management. Additionally, a key component in the literature identified the need to increase Indigenous community participation in policy and practice. It was evident that policy can support Indigenous engagement across all levels from governance to enactment (e.g., research fieldwork) (Jackson & Douglas, 2015), and existing conservation programs can be used to inform policy (Ens et al., 2016).

Capacity building for the benefit of community

A key component identified in the literature was opportunities for capacity building in Indigenous participation in STEM for the benefit of the community and fulfilling obligations in caring for Country. The literature evidenced engagement with Indigenous stakeholder groups was essential to sustain Country. This includes providing employment, skills development, resources, and tangible qualifications to the local community. This engagement was evident in community-based approaches to benefit the community such as community capacity building for Rangers (Jackson & Douglas, 2015). Another example is Indigenous people using ICTs for cultural purposes such as cultural heritage management, language teaching, and revitalisation.

Engagement and collaboration

The literature evidenced the need for collaboration with Indigenous peoples and stakeholders in terms of knowledge sharing and research processes. It highlighted the benefit of engagement and collaboration towards a more comprehensive knowledge set to improve ecological management strategies (Russell et al., 2021), and acknowledged partnerships that considered the unique context of each community when planning cross-cultural approaches in caring for Country

(Hoverman & Ayre, 2012). Authors valued meaningful partnerships that were community-based and collaborative (Currell et al., 2022; Stefanelli et al., 2017).

Evidence presented in the literature highlighted that Indigenous community capacity in land and sea management practices is built and improves when government agencies form relationships, engage and collaborate with Traditional Owners, Indigenous Elders, Rangers, and community. One example cited was approaches to rock art conservation and management practices which were implemented after working with Indigenous Elders and Rangers (Marshall, 2020). Another example cited was the strengths of the collaboration of Traditional Owners and government agencies to build community capacity towards sustainability for ongoing sea management (Hof et al., 2017).

Developing relations in co-management was documented as beneficial in sustaining relationships beyond project completion (Jackson & Douglas, 2015; Thomassin, 2019). However, alignment of community and academic interests is needed (Jackson & Douglas, 2015). One example is Rangers and researchers working together with technology to preserve cultural sites (Carmichael et al., 2020).

There was evidence of challenges to engagement and collaboration that impact Indigenous peoples' participation in environmental management and caring for Country. Also, there was misalignment between academic interests and community interests when environmental management projects were not co-designed. For example, research outputs can impact communication with Indigenous communities if it is not understood by the community (Jackson & Douglas, 2015).

Finally, the literature acknowledged a lack of awareness of protocols and ways to engage Indigenous peoples and relevant stakeholders in environmental management practices (Ockwell, 2008; Robinson et al., 2016). Non-Indigenous peoples' lack of cultural awareness also leads to Indigenous people experiencing racism and discrimination (Pearson & Daff, 2011), as well as cultural taxation on Indigenous research leaders (Ens & Turpin, 2022).

Limitations

This literature review was limited to the publications available from the pre-selected academic databases, which, therefore, does not consider grey literature. It is recognised that this may have excluded some Indigenous-authored material on the topic. The findings were also impacted by the time constraints of this project which was undertaken in an eight-month timeframe.

Conclusions and future research

Several key conclusions can be made from undertaking these systematic literature reviews. The literature was predominantly drawn from science-related fields, indicating that 'science' has become synonymous with 'STEM'. In education, mathematics was a secondary focus of the literature. Across the board, Indigenous participation with information technology supported cultural or environmental management practices, rather than in technology as a STEM discipline or career. Overall, engineering is often lacking in terms of research that promotes Indigenous participation.

Across the publications and in all STEM contexts, it was evident that Indigenous knowledges should be considered of equal value and importance as Western knowledges for increasing Indigenous participation. For example, across education, industry and caring for Country contexts, there was increased Indigenous participation in science-related engagements when Indigenous ecological science knowledges were valued and used alongside Western science knowledges.

Similarly in education contexts, there was increased Indigenous participation in mathematics settings when oral language and hands-on activities were paired with real world connections to Indigenous worldviews and cultures.

The literature highlights that recognition of Indigenous peoples as sovereign partners in governance, policy development and research in STEM is essential for increased participation. For education, this means involving Indigenous teachers, community, Elders, and family in the decision-making, development, and delivery of interventions. For industry or caring for Country, this means involving Indigenous stakeholders at all levels who contribute to all aspects of the project being undertaken (e.g., governance, decision-making and policy creation, and practices). Indigenous knowledges should also inform policy in the interest of environmental sustainability. This includes the presence of Indigenous STEM knowledges within Indigenous community-led and community-based models, which are holistic and relational, rather than being defined and fragmented into Western STEM categories. Furthermore, Indigenous participation is supported when non-Indigenous people build cultural awareness through consultation and engagement with Indigenous peoples.

For educational contexts, there is strong evidence supporting a shift of pedagogy towards practical, real-life learning styles, and involvement with parents, community, and Elders to improve engagement for Indigenous students (e.g., considering Indigenous peoples as cultural assets). Additionally, it was evident that teacher cultural awareness is not sufficient in ensuring active participation, as this does not consider supportive factors, impacting factors, and self-perceptions of Indigenous students that impact participation in STEM. There is also overwhelmingly a lack of Indigenous student voice regarding their engagement and participation, which would benefit the development of interventions.

In industry and caring for Country contexts, it was evident that on-Country opportunities for capacity building were necessary to ensure that Indigenous Australians could fulfill obligations in caring for Country and work to benefit the community. This includes providing skills development, resources, tangible qualifications, and employment opportunities for local community.

Across all contexts, ICT was used for cultural purposes and environmental management. To support ICT uptake, resources, infrastructure, and training in ICT use are required within Indigenous communities. ICT was seen as particularly valuable in the context of language and culture preservation, and land and sea management and conservation. Also, challenges specific to this context included data sovereignty and protection of Indigenous knowledges from wider dissemination and abuse when shared in online environments.

While the literature highlights strengths to increase Indigenous participation in areas of STEM, there is an overall lack of interventions with demonstrated sustainability and quantitative measures of participant outcomes. If an evaluation occurred, it was usually assessed qualitatively with self-reflection or interviews (most often from non-Indigenous participants). More than half of the publications were focused on remote communities, which is not reflective of current Indigenous population data across geolocations. There is also a lack of Indigenous authorship representation across the publications, with only two out of the 103 publications having sole Indigenous Australian authorship. While co-authorship with Indigenous Australian peoples is increasing, there needs to be greater representation of Indigenous authors in research pertaining to Indigenous participation. There was also an overwhelming absence of Torres Strait Islander voices in the literature and Indigenous participation most often referred to ‘Aboriginal participation’.

In conclusion, while there have been preliminary efforts to assess ways to increase Indigenous participation in STEM fields, there is need for more research on specific interventions that were deemed successful and sustainable.

References

Aldous, C., Barnes, A., & Clark, J. (2008). Engaging excellent Aboriginal students in science: An innovation in culturally-inclusive schooling. *Teaching Science*, *54*(4), 35–39. https://search.informit.org/doi/reader/10.3316/informit.416856851614902

Armour, D., Warren, E., & Miller, J. (2016). Working together: Strategies that support cross-cultural engagement of Indigenous teacher assistants working in Indigenous contexts. *Asia-Pacific Journal of Teacher Education, 44*(5), 421–435. https://doi.org/10.1080/1359866X.2015.1127324

Appanna, S. D. (2011). Embedding Indigenous perspectives in teaching school science. *Australian Journal of Indigenous Education, 40*, 18-22. https://doi.org/10.1375/ajie.40.18

Australian Bureau of Statistics. (2022, July 1). *Australia: Aboriginal and Torres Strait Islander population summary*. https://www.abs.gov.au/articles/australia-aboriginal-and-torres-strait-islander-population-summary#:~:text=In%202021%2C%2037.1%25%20of%20Aboriginal,lived%20in%20capital%20city%20areas.

Bohnet, I. C., Hill, R., Turton, S. M., Bell, R., Hilbert, D. W., Hinchley, D., Pressey, R. L., B., Rainbird, J., Standley, P-M., Cvitanovic, C., Crowley, G., Curnock, M., Dale, A., Lyons, P., Moran, C., & Pert, P. L. (2013, December). Supporting regional natural resource management (NRM) organisations to update their NRM plans for adaptation to climate change. *Proceedings of the 20th International Congress on Modelling and Simulation* (pp. 2214–2220). https://www.terranova.org.au/repository/wet-tropics-nrm-collection/supporting-regional-nrm-organisations-to-update-their-nrm-plans-for-adaptation-to-climate-change/bohnet-et-al-2013.pdf

Boisselle, L. N., & McLaughlin, M. (2021). Using the third space to address the microinvalidation of Indigenous science within mainstream science education classrooms: Trinidad and Tobago and Australia. In J. K. Corkett, C. L. Cho, & A. Steele (Eds.), *Global perspectives on microaggressions in schools: Understanding and combating covert violence* (pp. 128–144). Routledge.

Boon, H. J. (2012). Regional Queensland parents' views of science education: Some unexpected perceptions. *Australian Educational Researcher, 39*(1), 17–43. https://doi.org/10.1007/s13384-011-0045-5

Buckskin, P., Tranthim-Fryer, M., Holt, L., Gili, J., Heath, J., Smith, D., Larkin, S., Ireland, S., MacGibbon, L., Robertson, K., Small, T., Butler, K., Chatfield, T., Anderson, P., & Ma Rhea, Z. (2018). *NATSIHEC accelerating Indigenous higher education consultation paper.* National Aboriginal and Torres Strait Islander Higher Education Consortium, Australia. https://eprints.qut.edu.au/215558/

Carmichael, B., Wilson, G., Namarnyilk, I., Nadji, S., Cahill, J., Brockwell, S., Webb, B., Bird, D., & Daly, C. (2020). A methodology for the assessment of climate change adaptation options for cultural heritage sites. *Climate 2020, 8*(8), 88. https://doi.org/10.3390/CLI8080088

Carter, J., & Hill, G. (2007). Indigenous community-based fisheries in Australia. *Journal of Environmental Management, 85*(4), 866–875. https://doi.org/10.1016/j.jenvman.2006.10.021

Cooke, P. (1999). Fire management on Aboriginal lands in the top end of the Northern Territory, Australia. In J. Russell-Smith, G. Hill, S. Djoeroemana, & B. Myers, *Fire and sustainable agricultural and forestry development in Eastern Indonesia and Northern Australia* (pp. 102-107). Australian Centre for International Agricultural Research. https://www.aciar.gov.au/sites/default/files/legacy/node/2117/pr91_pdf_11455.pdf#page=103

Cooper, G., & Berry, A. (2020). Demographic predictors of senior secondary participation in biology, physics, chemistry and earth/space sciences: Students' access to cultural, social and science capital. *International Journal of Science Education, 42*(1), 151–166. https://doi.org/10.1080/09500693.2019.1708510

Crough, J. A. (2015). *People, place and practices: Digital technologies in the changing world of fire management in Northern Australia.* [Doctoral dissertation, Charles Darwin University]. https://doi.org/10.25913/5ea6749b2c657

Cullen-Unsworth, L. C., Hill, R., Butler, J. R. A., & Wallace, M. (2012). A research process for integrating Indigenous and scientific knowledge in cultural landscapes: Principles and determinants of success in the Wet Tropics World Heritage Area, Australia. *Geographical Journal, 178*(4), 351–365. https://doi.org/10.1111/j.1475-4959.2011.00451.x

Currell, M., Hansen, C., Nicholson, R., Esmond, M., & Dooley, K. (2022). Designing a monitoring program and conceptual models to protect ecological and cultural values of waterways vulnerable to coal seam gas impacts. *Hydrology and Water Resources Symposium (HWRS 2022): The past, the present, the future* (pp. 912–923). Engineers Australia.

Darcy, R., & Auld, G. (2008). The production and distribution of Burarra talking books. *Australian Educational Computing, 23*(1), 19-23. https://dro.deakin.edu.au/articles/journal_contribution/The_production_and_distribution_of_Burarra_talking_books/20868823/1

Davies, J., & Holcombe, S. (2009). Desert knowledge: Integrating knowledge and development in arid and semi-arid drylands. *GeoJournal, 74*(5), 363–375. https://doi.org/10.1007/s10708-009-9279-4

De Lemos, M. M. (1979). *Aboriginal students in Victoria. ACER research monograph no. 3.* Australian Council for Educational Research. http://files.eric.ed.gov/fulltext/ED175619.pdf

Donovan, M. (2018). Local collaboration to grow the seeds of STEM investment from school and beyond. *International Journal of Innovation in Science and Mathematics Education, 26*(2), 3–13. https://openjournals.library.sydney.edu.au/index.php/CAL/article/view/12374

Ens, E. J. (2012). Monitoring outcomes of environmental service provision in low socio-economic Indigenous Australia using innovative CyberTracker technology. *Conservation and Society, 10*(1), 42–52. https://doi.org/10.4103/0972-4923.92194

Ens, E. J., Pert, P., Clarke, P. A., Budden, M., Clubb, L., Doran, B., Douras, C., Gaikwad, J., Gott, B., Leonard, S., Locke, J., Packer, J., Turpin, G., & Wason, S. (2015). Indigenous biocultural knowledge in ecosystem science and management: Review and insight from Australia. *Biological Conservation, 181,* 133–149. https://doi.org/10.1016/j.biocon.2014.11.008

Ens, E. J., & Turpin, G. (2022). Synthesis of Australian cross-cultural ecology featuring a decade of annual Indigenous ecological knowledge symposia at the Ecological Society of Australia conferences. *Ecological Management & Restoration, 23*(1), 3–16. https://doi.org/10.1111/emr.12539

Ens, E., Scott, M. L., Rangers, Y. M., Moritz, C., & Pirzl, R. (2016). Putting Indigenous conservation policy into practice delivers biodiversity and cultural benefits. *Biodiversity and Conservation, 25*(14), 2889–2906. https://doi.org/10.1007/s10531-016-1207-6

Ewing, B. (2011). Direct instruction in mathematics: Issues for schools with high Indigenous enrolments: A literature review. *Australian Journal of Teacher Education, 36*(5), 64–91. https://doi.org/10.14221/ajte.2011v36n5.5

Ewing, B. (2014). Rich and purposeful mathematical knowledge of mothers and children in a Torres Strait Islander community. *SpringerPlus, 3*(1), 42–42. https://doi.org/10.1186/2193-1801-3-42

Ewing, B. (2017). An exploration of assessment approaches in a vocational and education training courses in Australia. *Empirical Research in Vocational Education and Training, 9*(1), 1–18. https://doi.org/10.1186/s40461-017-0058-z

Fache, E., & Moizo, B. (2015). Do burning practices contribute to caring for country? Contemporary uses of fire for conservation purposes in Indigenous Australia. *Journal of Ethnobiology, 35*(1), 163–182. https://doi.org/10.2993/0278-0771-35.1.163

Fisher, R., Heckbert, S., & Garnett, S. (2021). Reframing wildfire simulations for understanding complex human-landscape interactions in cross-cultural contexts: A case study from Northern Australia. *Fire, 4*(3), 46. https://doi.org/10.3390/fire4030046

Frantzeskaki, N., Oke, C., Barnett, G., Bekessy, S., Bush, J., Fitzsimons, J., Ignatieva, M., Kendal, D., Kingsley, J., Mumaw, L., & Ossola, A. (2022). A transformative mission for prioritising nature in Australian cities. *Ambio, 51*(6), 1433–1445. https://doi.org/10.1007/s13280-022-01725-z

Fraser, S., Barnes, N., Kilpatrick, S., Guenther, J., & Nutton, G. (2021). Considering young people's dislocation from STEM education: Looking beyond the narrow focus of teaching and learning practice within school. *Frontiers in Education, 6,* 1-14. https://doi.org/10.3389/feduc.2021.678613

Goldfinch, T., Prpic, J. K., Jolly, L., Leigh, E., & Kennedy, J. (2017). Australian engineering educators' attitudes towards Aboriginal cultures and perspectives. *European Journal of Engineering Education, 42*(4), 429–444. https://doi.org/10.1080/03043797.2017.1328588

Grafton, R. Q., Colloff, M. J., Marshall, V., & Williams, J. (2020). Confronting a 'post-truth water world' in the Murray-Darling Basin, Australia. *Water Alternatives, 13*(1), 1–27. https://openresearch-repository.anu.edu.au/bitstream/1885/258256/1/01_Grafton_Confronting_a_%2527post-truth_2020.pdf

Grey-Gardner, R. (2008). Implementing risk management for water supplies: A catalyst and incentive for change. *Rangeland Journal, 30*(1), 149–156. https://doi.org/10.1071/RJ07046

Grootenboer, P., & Sullivan, P. (2013). Remote Indigenous students' understandings of measurement. *International Journal of Science and Mathematics Education, 11*(1), 169–189. https://doi.org/10.1007/s10763-012-9383-7

Hardy, D., Forest, E., McIntosh, Z., Gertz, J., & Myers, T. (2016a). Co-creation of a digital game to support language revitalisation. In Y. Luo (Ed.), *Cooperative design, visualization, and engineering* (pp. 181-184). Springer International Publishing.

Hardy, D., Forest, E., McIntosh, Z., Myers, T., & Gertz, J. (2016b, November). Moving beyond "just tell me what to code": Inducting tertiary ICT students into research methods with Aboriginal participants via games design. *Proceedings of the 28th Australian Conference on Computer-Human Interaction* (pp. 557–561). https://doi.org/10.1145/3010915.3010991

Hayashi, Y., Christie, M., Gaillard, J. C., Banks, E. W., Batelaan, O., & Ellis, J. (2021). A transdisciplinary engagement with Australian Aboriginal water and the hydrology of a small bedrock island. *Hydrological Sciences Journal, 66*(13), 1845–1856. https://doi.org/10.1080/02626667.2021.1974025

Hemming, S., Rigney, D., Muller, S. L., Rigney, G., & Campbell, I. (2017). A new direction for water management? Indigenous nation building as a strategy for river health. *Ecology and Society, 22*(2), 13. https://doi.org/10.5751/ES-08982-220213

Hof, C. A. M., Smallwood, E., Meager, J., & Bell, I. P. (2017). First citizen-science population abundance and growth rate estimates for green sea turtles Chelonia mydas foraging in the northern Great Barrier Reef, Australia. *Marine Ecology. Progress Series*, *574*, 181–191. https://doi.org/10.3354/meps12173 42

Hoverman, S., & Ayre, M. (2012). Methods and approaches to support Indigenous water planning: An example from the Tiwi Islands, Northern Territory, Australia. *Journal of Hydrology, 474*, 47–56. https://doi.org/10.1016/j.jhydrol.2012.03.005

Howard, P. & Perry, B. (2007). A school-community model for enhancing Aboriginal students' mathematical learning. In J. Watson & K. Beswick (Eds.), *Proceedings of the 30th annual conference of the Mathematics Education Research Group of Australasia* (pp. 402-411). MERGA. https://files.eric.ed.gov/fulltext/ED503746.pdf

Howlett, C., Seini, M., Matthews, C., Dillon, B., & Hauser, V. (2008). Retaining Indigenous students in tertiary education: Lessons from the Griffith school of environment. *Australian Journal of Indigenous Education, 37*(1), 18–27. https://doi.org/10.1017/S1326011100016057

Humphreys, P. (1995). *Innovative links project, St. Paul's catholic school, Nightcliff: Cultural responsiveness and cultural diversity.* https://files.eric.ed.gov/fulltext/ED386283.pdf

Jackson, S. E., & Douglas, M. (2015). Indigenous engagement in tropical river research in Australia: The TRaCK Program. *International Indigenous Policy Journal, 6*(2), 3. https://doi.org/10.18584/iipj.2015.6.2.3

Jamie, J. F. (2021). Macquarie-Yaegl partnership: Community capability strengthening through Western and Indigenous Science. *Australian Journal of Chemistry, 74*(1), 28–33. https://doi.org/10.1071/CH20248

Jellinek, S., Lloyd, S., Catterall, C., & Sato, C. (2021). Facilitating collaborations between researchers and practitioners in ecosystem management and restoration. *Ecological Management & Restoration, 22*(2), 208-213. https://doi.org/10.1111/emr.12465

Jennings, A. C. (2021). Advancing local, social, and ecological transitions through community development. In J. Boulet & L. Hawkins (Eds.), *Practical and political approaches to recontextualizing social work.* IGI Global.

Koenig, J. (2007). *'Too many trees!': Indigenous woodcarving and harvest sustainability in central Arnhem Land*. [Doctoral Dissertation, Charles Darwin University]. ProQuest Dissertations Publishing. https://doi.org/10.25913/5e8c0e3d8dae9

Kutay, C. (2007). Knowledge management as enterprise. *Australian Journal of Indigenous Education*, *36*(1), 137–44. https://doi.org/10.1017/S1326011100004816.

Kutay, C. (2021). Knowledge elicitation with Aboriginal Australian communities. *Australasian Journal of Information Systems, 25*, 1–21. https://doi.org/10.3127/AJIS.V25I0.2907

Kutay, C., Fisher, G., & Green, R. (2010). Flexible IT resources for community language reclamation: Using culturally appropriate contexts. In J. Hobson, K. Lowe, S. Poetsch, & M. Walks (Eds.), *Reawakening languages: Theory and practice in the revitalisation of Australia's Indigenous languages*. Sydney University Press.

Lilleyman, A., Millar, G., Burn, S., Fatt, K. H., Talbot, A., Que-Noy, J., Dawson, S., Williams, B., Mummery, A., Rolland, S., Wilson, S., Jacobson, E., & Smith, B. C. D. (2022). Indigenous knowledge in conservation science and the process of a two-way research collaboration. *Conservation Science and Practice, 4*(8), 1–10. https://doi.org/10.1111/csp2.12727

Lyons, I., & Barber, M. (2021). Relatedness and co-existence in water resource assessments: Indigenous water values, rights and interests in the Mitchell catchment, North Queensland. *Australian Journal of Water Resources, 25*(1), 57–69. https://doi.org/10.1080/13241583.2021.1921331

Makuwira, J. (2008). Towards pedagogies of mathematics achievement: An analysis of learning advisers' approaches to the tutoring of mathematics in the Indigenous tertiary entry program. *Australian Journal of Indigenous Education, 37*(1), 48–55. https://doi.org/10.1017/S1326011100016082

Marshall, M. R. (2020). *Rock art conservation and management: 21st century perspectives from Northern Australia*. [Doctoral dissertation, Australian National University]. ProQuest Dissertations Publishing. https://openresearch-repository.anu.edu.au/handle/1885/204736

Matthews, C. (2012). Maths as storytelling: Maths is beautiful. In K. Price (Ed.), *Aboriginal and Torres Strait Islander education: An introduction for the teaching profession* (pp. 94–112). Cambridge University Press.

McConney, A., Oliver, M., Woods-McConney, A., & Schibeci, R. (2011). Bridging the gap? A comparative, retrospective analysis of science literacy and interest in science for Indigenous and non-Indigenous Australian students. *International Journal of Science Education, 33*(14), 2017–2035. https://doi.org/10.1080/09500693.2010.529477

McInerney, D. M. (1990). *Some demographic and scholastic variables influencing school retention: A cross-cultural comparison*. https://files.eric.ed.gov/fulltext/ED352574.pdf

McKemey, M., Ens, E., Rangers, Y. M., Costello, O., & Reid, N. (2020). Indigenous knowledge and seasonal calendar inform adaptive savanna burning in Northern Australia. *Sustainability, 12(*3), 1–18. https://doi.org/10.3390/su12030995

Michie, M., Hogue, M., & Rioux, J. (2018). The application of both-ways and two-eyed seeing pedagogy: Reflections on engaging and teaching science to post-secondary Indigenous students. *Research in Science Education (Australasian Science Education Research Association), 48*(6),1205–1220. https://doi.org/10.1007/s11165-018-9775-y

Milgin, A., Nardea, L., Grey, H., Laborde, S., Jackson, S., & Wehi, P. (2020). Sustainability crises are crises of relationship: Learning from Nyikina ecology and ethics. *People and Nature, 2*(4), 1210–1222. https://doi.org/10.1002/pan3.10149

Niesche, C. (2023, June). Soaring to new heights: Aerospace technology business analyst and proud Gomeroi woman Josie Collins CPA draws on her leadership skills to bring more First Nations people into the profession. *INTHEBLACK*. https://intheblack-magazine.cpaaustralia.com.au/cpa-australia/intheblack-june-2023?pid=MzI328932&v=2.1

Ockwell, D. G. (2008). 'Opening up' policy to reflexive appraisal: A role for Q methodology? A case study of fire management in Cape York, Australia. *Policy Sciences, 41*(4), 263–292. https://doi.org/10.1007/s11077-008-9066-y

Papic, M. M., Mulligan, J. T., Highfield, K., McKay-Tempest, J., & Garrett, D. (2015). The impact of a patterns and early algebra program on children in transition to school in Australian Indigenous Communities. In B. Perry, A. MacDonald, & A. Gervasoni (Eds.), *Mathematics and transition to school* (pp. 217–236). Springer Singapore. https://doi.org/10.1007/978-981-287-215-9_14

Pearson, C. A., & Daff, S. (2011). Extending boundaries of human resource concepts and practices: An innovative recruitment method for Indigenous Australians in remote regions. *Asia Pacific Journal of Human Resources, 49*(3), 325–343. https://doi.org/10.1177/1038411111414380

Pearson, C. A., & Daff, S. (2013). Transcending hunter gatherer pursuits while balancing customary cultural ideals with market forces of advanced western societies: Extending the traditional boundaries of Indigenous Yolngu people of the Northern Territory of Australia. *International Journal of Cultural Studies, 16*(2), 189–208. https://doi.org/10.1177/1367877912452487

Phillips, C. (2017). Ghostly encounters: Dealing with ghost gear in the Gulf of Carpentaria. *Geoforum, 78*, 33–42. https://doi.org/10.1016/j.geoforum.2016.11.010

Reed, G., Brunet, N. D., Longboat, S., & Natcher, D. C. (2021). Indigenous guardians as an emerging approach to Indigenous environmental governance. *Conservation Biology, 35*(1), 179–189. https://doi.org/10.1111/cobi.13532

Renowden, C., Beer, T., & Mata, L. (2022). Exploring integrated ArtScience experiences to foster nature connectedness through head, heart and hand. *People and Nature, 4*(2), 519–533. https://doi.org/10.1002/pan3.10301

Rigney, L., Garrett, R., Curry, M., & MacGill, B. (2020). Culturally responsive pedagogy and mathematics through creative and body-based learning: Urban Aboriginal schooling. *Education and Urban Society, 52*(8), 1159–1180. https://doi.org/10.1177/0013124519896861

Rioux, J., Ewing, B., & Cooper, T. (2018). Two-way conflation of home and school realities: Local science and Linnaean language in the biology curriculum. *Australian Aboriginal Studies,* (1), 57–71. https://eprints.qut.edu.au/119469/

Rioux, J., Ewing, B., & Cooper, T. J. (2021). The Montessori method, Aboriginal students and Linnaean zoology taxonomy teaching: Three-staged lesson. *Australian Journal of Indigenous Education, 50*(1), 116–126. https://doi.org/10.1017/jie.2019.10

Rioux, J., & Smith, G. (2019). Both-ways science education: Place and context. *Learning Communities: International Journal of Learning in Social Contexts*, (25), 90-105. doi: 10.18793/lcj2019.25.09

Robertson, H., Ross-Symonds, D., & Connolly, P. (2020). Designing the Olkola Cultural Knowledge Centre: A traditional owner-led integrated research and education process. *Proceedings of the 54th International Conference of the Architectural Science Association (ANZAScA) 2020* (pp. 375–384). https://rest.neptune-prod.its.unimelb.edu.au/server/api/core/bitstreams/1bf18b83-3148-5856-9fbd-7b0ef63ffd96/content

Robinson, C. J., Maclean, K., Hill, R., Bock, E., & Rist, P. (2016). Participatory mapping to negotiate indigenous knowledge used to assess environmental risk. *Sustainability Science, 11*(1), 115–126. https://doi.org/10.1007/s11625-015-0292-x

Ruddell, N. (2021). Mutual cultural responsivity: Towards a framework for contemporary school science – An open letter to educators and school communities. *Teaching Science, 67*(1), 31–34. https://search.informit.org/doi/reader/10.3316/informit.674923503540972

Russell, S., & Ens, E. (2020). Connection as Country: Relational values of billabongs in Indigenous Northern Australia. *Ecosystem Services, 45*(101169), 1-11. https://doi.org/10.1016/j.ecoser.2020.101169

Russell, S., Ens, E., & Rangers, N. Y. (2021). 'Now it's not a billabong': Eco-cultural assessment of billabong condition in remote Northern Australia. *Marine and Freshwater Research, 72*(7), 925–941. https://doi.org/10.1071/MF20080

Sammell, A., & Whatman, S. (2018). A novel approach to developing literacies in Indigenous knowledge systems and Western science knowledge: Lessons for primary school students in Australia. *Journal of Australian Indigenous Issues, 21*(1-2), 40-60. https://search.informit.org/doi/epdf/10.3316/informit.142709945493006

Siemon, D. E. (2009). Developing mathematics knowledge keepers: Issues at the intersection of communities of practice. *Eurasia Journal of Mathematics, Science and Technology Education, 5*(3), 221–234. https://doi.org/10.12973/ejmste/75274

Singleton, G., Rola-Rubzen, M. F., Muir, K., Muir, D., & McGregor, M. (2009). Youth empowerment and information and communication technologies: A case study of a remote Australian Aboriginal community. *GeoJournal, 74*(5), 403–413. https://doi.org/10.1007/s10708-009-9277-6

Smith, U., Knight, G., Lovett-Murray, T., Rose, D., & Henry, D. (2018). The field guide to the Budj Bim cultural landscape app: A partnership between the Gunditjmara community and museums Victoria. *Biodiversity Information Science and Standards.* https://doi.org/10.3897/biss.2.26891

Stefanelli, R. D., Castleden, H., Harper, S. L., Martin, D., Cunsolo, A., & Hart, C. (2017). Experiences with integrative Indigenous and Western knowledge in water research and management. *Environmental Reviews, 25*(3), 323–333. https://doi.org/10.1139/er-2016-0114

Thomassin, A. (2019). *'Ina ngalmun lagau malu' (this part of the sea belongs to us): Politics, sea rights and fisheries co-management in Zenadh Kes (Torres Strait)*. [Doctoral dissertation, McGill University]. ProQuest Dissertations Publishing.

Thornton, S., Giles, W., Prescott, D., & Rhodes, D. (2011). Exploring the mathematical confidence of Indigenous preservice teachers in a remote teacher education program. *Mathematics Education Research Journal, 23*(2), 235–252. https://doi.org/10.1007/s13394-011-0013-4

Thwaite, A. (2014). Teachers and teacher aides initiating five-year-olds into science. *Functional Linguistics, 1*(1), 1. https://doi.org/10.1186/2196-419X-1-6

Treagust, D. F., Malone, J. A., Fraser, B. J., & Taylor, P. C. (1987, April). *Bridging programs for Aborigines wishing to study science and mathematics in higher education* [Symposium presentation]. Participation and equity in education – Some Australian case studies. American Educational Research Association, Washington, D.C. https://files.eric.ed.gov/fulltext/ED282725.pdf

Trimmer, K., Gower, G., & Lock, G. (2018). Reinventing another Unaipon: Indigenous science leaders for the future. *Australian Journal of Indigenous Education, 47*(2), 216–225. https://doi.org/10.1017/jie.2017.14

Vaarzon-Morel, P., & Kelly, L. (2019). Enlivening people and country: The Lander Warlpiri cultural mapping project. In L. Barwick, J. Green, & P. Vaarzon-Morel (Eds.), *Archival returns: Central Australia and beyond* (pp.111–138). University of Hawai'i Press & Sydney University Press. http://hdl.handle.net/10125/24880

Verschuuren, B. (2017). *Creating common ground: The role of Indigenous peoples' sacred natural sites in conservation practice, management and policy*. [Doctoral dissertation, Wageningen University]. ProQuest Dissertations Publishing.

Warren, E., & Miller, J. (2013). Young Australian Indigenous students' effective engagement in mathematics: The role of language, patterns, and structure. *Mathematics Education Research Journal, 25*(1), 151–171. https://doi.org/10.1007/s13394-013-0068-5

Warren, E. A., Quine, J., & deVries, E. (2012). Supporting teachers' professional learning at a distance: A model for change in at-risk contexts. *Australian Journal of Teacher Education, 37*(6), 12–28. https://doi.org/10.14221/ajte.2012v37n6.1

Warren, E., Young, J., & deVries, E. (2007). Australian Indigenous students: The role of oral language and representations in the negotiation of mathematical understanding. In J. Watson & K. Beswick (Eds.), *Proceedings of the 30th annual conference of the Mathematics Education Research Group of Australasia* (pp.775-784). MERGA. https://files.eric.ed.gov/fulltext/ED503746.pdf

Warren, E., Young, J., & deVries, E. (2008). The impact of early numeracy engagement on four-year-old Indigenous students. *Australasian Journal of Early Childhood, 33*(4), 2–8. https://doi.org/10.1177/183693910803300402

Weir, J. K. (2021). Terrain: De/centring environmental management with Indigenous peoples' leadership. *Borderlands e-Journal, 20*(1), 171–206. https://doi.org/10.21307/borderlands-2021-007

Wergin, C. H. (2018). Collaborations of biocultural hope: Community science against industrialisation in northwest Australia. *Ethnos, 83*(3), 455–472. https://doi.org/10.1080/00141844.2016.1169203

Wilcock, D. A. (2013). *Living landscapes: 'Ethnogeomorphology' as an ethical frame of communication in environmental decision-making.* [Doctoral dissertation, York University]. Library and Archives Canada.

Wilson, G. R., Edwards, M. J., & Smits, J. K. (2010). Support for Indigenous wildlife management in Australia to enable sustainable use. *Wildlife Research, 37*(3), 255–263. https://doi.org/10.1071/WR09130

Wilson, K., & Alloway, T. (2013). Expecting the unexpected: Engaging diverse young people in conversations around science. *Australian Educational Researcher, 40*(2), 195–206. https://doi.org/10.1007/s13384-012-0084-6

Wood, S. W., Ward, C., & Bowman, D. M. J. S. (2017). Substrate controls growth rates of the woody pioneer leptospermum lanigerum colonizing montane grasslands in northern Tasmania. *Austral Ecology, 42*(1), 9–19. https://doi.org/10.1111/aec.12390

Woodley, C. J., Fagan, S., & Marshall, S. (2014). Wadawurrung Dya Baap Ngobeeyt: Teaching spatial mapping technologies. *Campus-Wide Information Systems, 31*(4), 276–287. https://doi.org/10.1108/CWIS-10-2013-0059

Woodley, C., Marshall, S., Taylor, S., & Fagan, S. (2013). Technologies, Indigenous cultural heritage and community capacity building. *2013 IEEE Global Humanitarian Technology Conference (GHTC)*, 406–410. https://doi.org/10.1109/GHTC.2013.6713720

Woods-McConney, A., Oliver, M. C., McConney, A., Maor, D., & Schibeci, R. (2013). Science engagement and literacy: A retrospective analysis for Indigenous and non-Indigenous students in Aotearoa New Zealand and Australia. *Research in Science Education, 43*(1), 233–252. https://doi.org/10.1007/s11165-011-9265-y

Yeung, A. S., Craven, R. G., & Ali, J. (2013). Self-concepts and educational outcomes of Indigenous Australian students in urban and rural school settings. *School Psychology International, 34*(4), 405–427. https://doi.org/10.1177/0143034312446890

Study 2: Survey analysis

Who participated in the survey?

To understand the findings presented, it is essential to know who participated in the *Big Mob: STEM It Up* survey. As mentioned in the research design, the survey was distributed using a community snowballing recruitment across Australia. In total, 204 Indigenous people across Australia participated in the survey. **Figure 17** captures the diversity of the voices heard in the survey.

Figure 17
Cultural Representation of Participants

The ages of the participants ranged from 18 years – 74 years (average age: 33.69 years) and included responses from a diverse gender population: 145 female participants (71%); 53 male participants (25.9%); and five non-binary participants (2.45%).

To understand the representation of Aboriginal and Torres Strait Islander people participating in the survey, participants were asked to share ‘Who is your mob?’. The responses given by participants have been displayed in **Table 7**. In total, there were 98 different ways in which participants identified mob. There were 28 participants who indicated they were unsure and four participants did not provide responses.

Table 7
Participant Responses to the Question 'Who Is Your Mob?'

Mob					
Arrente (1)	Bungalung (1)	Goreng Goreng & Gubbi Gubbi (1)	Koa & others (1)	Noongar & lama lama (1)	Wakka Wakka & Goreng Goreng (1)
Anaiwan (1)	Burri Gubba & Gorreng Gorreng (1)	Goreng-Goreng, Birrigubba & Kubi Kubi (1)	Koa, Kuku Yalanji, with traditional ties to the Wakka Wakka peoples (1)	Nukunu (6)	Wakka Wakka & Kalkadoon (1)
Arrentre (1)	Bungalung, Minjumbal Tribe (1)	Gunai Kurnai (4)	Koko Muluridji East Arm Darwin (1)	Nyikina (1)	Wiradjuri (24)
Atjinuri (1)	Culbong Parfitt (1)	Gumbaynggirr (1)	Koori mob, yorta yorta (1)	Pairebeenne Trawlwoolway (1)	Wiradjuri & bundjalung (2)
Awabakal & Worimi (1)	Darug (1)	Gumbaynggirr, Yuin & Wiradjuri (1)	Maraura (1)	Palawa (1)	Wiradjuri & Darug (1)
Adtjala (1)	Darug & Wonnarua (1)	Gunggari (1)	Kuku Yalanji (1)	Quandamooka (4)	Wiradjuri & Kamilaroi (1)
Badu & Boigu Zenadth Kes (1)	Dhanggati (1)	Gunngandji & Coconut Island (1)	Mandandanji (4)	Tagalaka & Waanyi (1)	Wiradjuri, Wonnarua & Yuin. (1)
Bailai (1)	Dhunagyy (1)	Iningai (2)	Mer Island, Erub Island (Torres Strait) Bindal, Juru, Kaangu (Aboriginal) (1)	Quandamooka & Minjungbal (1)	Wiradjurri (3)
Bayali (1)	Dunghutti & Yuin (1)	Jagera (1)	Meriam, Meuram tribe, Mer (murray island) Eastern Torres Strait (1)	Saibai Island (1)	Wodi Wodi (1)
Bindal (3)	Gamilaraay (2)	Jawoyn, Gurindji, Waany & Tagalaka (1)	Masig (1)	Taribelang Bunda (1)	Woppaburra (2)
Bindal, Birriah (1)	Gamilaroi (3)	Juru (1)	Narrandera – Wiradyuri Country (1)	Trawlwoolway (1)	Wulli Wulli, Bidijara & Ghungalu (1)
Bindal & Waka Waka (1)	Garigal, Awabakal, Darug & Wiradjuri (1)	Kabbi Kabbi (1)	Ngadjuri (1)	Waanyi (1)	Yuin (8)
Bindal & Birah (1)	Ghungalu (1)	Kala lagaw ya (1)	Nganâ, Gimerri & Wagiman (1)	Wadi Wadi (1)	Yuwaalaraay (1)
Biripi & Worimi (2)	Gooreng & Taribelang Bunda (1)	Kalkadoon (1)	Ngarrindjeri (1)	Wadjuk (1)	
Boigu Island (Torres Straits) (1)	Gooreng Gooreng (2)	Kalkadoon & Wakka Wakka (1)	Ngugi Mob & Minjerribah/Terrangeri (1)	Wagiman (3)	
Bundjalung (4)	Gooreng Gooreng & Wakka Wakka (2)	Kamilaroi (6)	Ngurrabul (1)	Wakka Wakka (3)	Unsure (28)
Bundjalung & Yuin (1)	Goreng Goreng & Birrigubba (1)	Kamilaroi & Gubbi Gubbi (1)	Nookunuh (1)	Wakka Wakka & Kabbi Kabbi (1)	Did not respond (4)

NB: The bracketed number indicates the number of participants who provided that response.

While English was indicated as the language spoken by participants (170/204 participants), there were also participants who indicated they were bilingual or multilingual. **Table 8** lists of all languages indicated by participants.

Table 8
Languages Spoken as Identified by Participants

Languages spoken identified by participants			
Aboriginal English (Gooreng Gooreng) (1)	English, Gamilaraay (1)	English, Darug (1)	Ours English akso (1)
Gooreng Gooreng (1)	English, Badtjala (1)	English, Dharug (1)	Torres Strait creole (2)
English and some Wiradyuri (3)	English and Bahasa Melayu (Malay) (1)	English, French, German (1)	Torres Strait creole, English (1)
English, Wiradjuri (1)	English and learning Jandai (1)	English, Palawa Kani (1)	Wakka Wakka, Aboriginal English (1)
English, Dhanggati Yawari (1)	English, Noongar (1)	English, Samoan (1)	Wuthathi (1)
English and some Gamilaraay (1)	English, Yeeralaraay (1)	English, Yuwaalaraay (1)	English (170)

NB: Four participants did not provide responses.

Participants were located across each of the territories and states (as indicated in **Table 9**) with majority of participants located in major cities.

Table 9
Participants' Current Place of Residence

State	Major cities	Inner regional	Outer regional	Remote/Very remote	*Total*
Queensland	58	10	15*	3	*86*
New South Wales	85	8	2	0	*95*
Victoria	10	0	0	0	*10*
South Australia	4	0	0	0	*4*
Australian Capital Territory	3*	0	0	0	*3*
Northern Territory	0	0	2	0	*2*
Western Australia	2	0	0	0	*2*
Total	*162*	*18*	*19*	*3*	*202^*

*One participant is represented twice in the data as they identified they live across two locations.

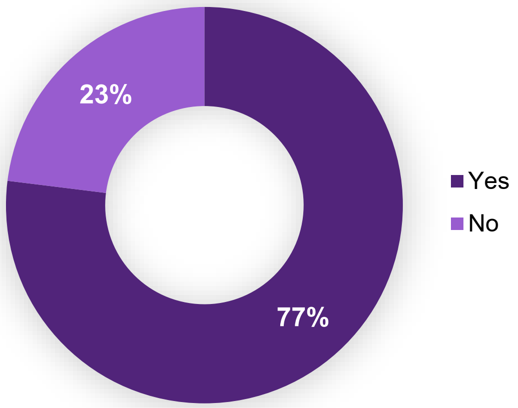
^Three participants did not provide specific location data.

Most participants identified that they were either employed (42.6%), studying (15.8%), or both studying and employed (22.8%), while a small number of participants reported that they were retired (3.5%). Some participants also identified their current activity as 'Other' (12.9%). Examples of 'Other' activity included home duties (e.g., full-time parent or carer), volunteering, or between employment. A small number of participants identified engaging in these 'Other' activities in addition to studying or working (1.5%) and retirement (1.0%).

Perspectives with STEM

To first gauge community's familiarity and perspectives with STEM, participants were asked to report whether they had heard of the term STEM. While 157 participants (77.0%) had heard of STEM, 47 (23%) had not (see **Figure 18**). If community members identified that they were unfamiliar with the term STEM, they were provided with the following definition before progressing further with the survey: *STEM is used an overarching term to represent Science, Technology, Engineering and Mathematics. These can be considered as single areas or draw on the concepts and skills from across any of these four areas to help us solve real world problems.*

Figure 18
Participants Responses to the Question 'Have you Heard of the Term STEM?'



If participants responded that they had heard of STEM, they were asked how they would describe STEM. In total, 115 participants provided a response. Analysis of this item is presented in **Table 10**.

Table 10
Participant Responses to the Question 'How Would You Describe STEM?'

How would you describe STEM?	Total number of participants
STEM acronym (e.g., science, technology, engineering, and mathematics) or combinations of the STEM acronym (e.g., science and technology; science and mathematics).	*76*
Education or learning (e.g., an approach to learning to integrate STEM)	*21*
Higher ordered thinking (e.g., innovation, creativity, problem-solving)	*4*
Career or industry (e.g., an industry that is extremely expansive and has many opportunities to engage)	*5*
Other responses (e.g., it is a service, it is great, leads us together, family and study)	*9*
Total	*115*

Participants were then asked to provide a response to the question 'What do you think of when you hear the word STEM?'. This question was asked to being to better understand the perspectives participants may have regarding STEM. In total, there were 203 responses. **Table 11** presents the most common themes from the analysis.

Table 11
Participant Responses to the Question 'What Do You Think of When You Hear the Word STEM?'

What do you think of when you hear the word STEM?	Total number of participants
Science, scientists	*45*
Education or learning	*44*
Nature	*22*
STEM acronym	*10*
Higher ordered thinking and innovation	*10*
Technologies and robots	*8*
Women in STEM	*6*
Careers	*5*
First Nations knowledges	*4*
Western knowledge systems/colonial construct	*4*

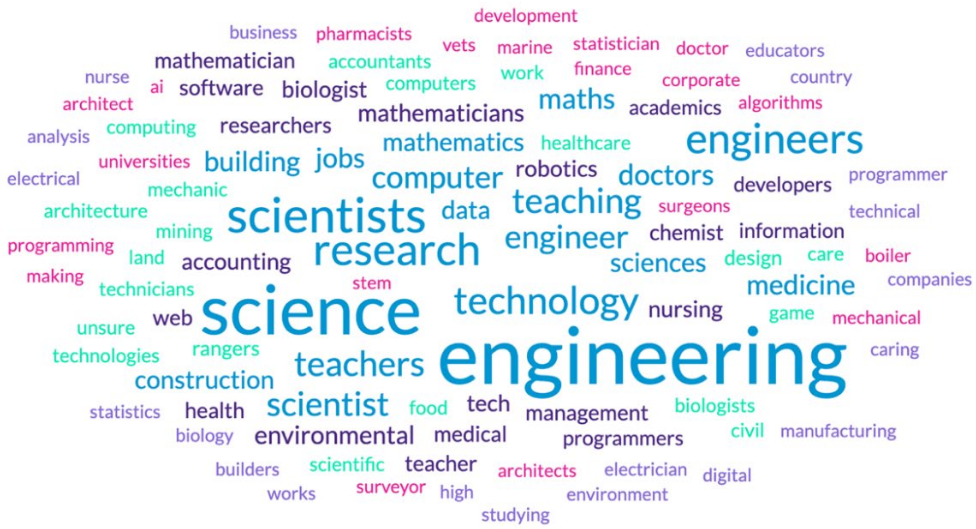
Jobs associated with STEM

Participants were asked to identify STEM careers, of which many participants responded that most or all jobs have aspects of STEM. For example:

> *All jobs involve STEM… How STEM is used today makes me think more about 'hard science' jobs, in industry, academia etc from applied biologists to science teachers to theoretical mathematicians with advancing AI technologies.*

Figure 19 is a generated word cloud of the types of responses provided by participants. Few participants were unable to provide a STEM career (n=5).

Figure 19
Identified STEM Careers



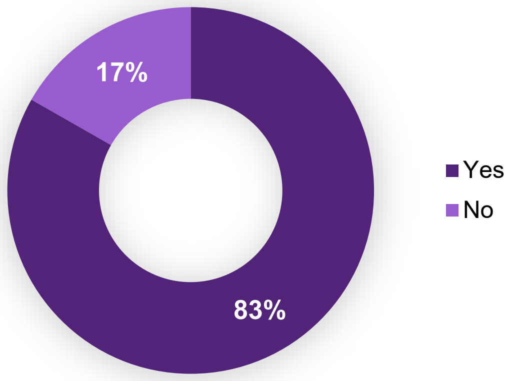
Some participants (n=10) shared how STEM careers were connected to Indigenous knowledges, including caring for Country, land and sea management, bush tucker, and traditional tools and artefacts.

> *Jobs in STEM are incredibly diverse - in my current role key Aboriginal scholars are investigating the digital lives of Indigenous people - even this fits broadly into technology. From scientists, to engineers, to people working as Rangers caring for Country, to maths and sciences teachers in school, to primary teachers and early childhood educators.*

Connections to culture

When asked whether participants saw a connection between STEM and their culture, 83.3% (169 of 203 participants) said they see a connection, whereas 16.7% (34 of 203) did not see a connection (see **Figure 20**).

Figure 20
Participant Responses to Seeing a Connection Between STEM and Their Culture



Common points identified by participants when explaining why they saw a connection between their culture and STEM included: (i) traditional knowledge systems that evidence that Aboriginal and Torres Strait Islander people are the first scientists of the lands; (ii) connection to, and caring for, Country; and (iii) innovations in technologies and engineering through traditional knowledges. To provide further context, the following excerpts are shared from the survey:

> *… Our people have been observing, hypothesising, and developing legitimate understandings of reality/ies for millenia. Sciences is not just a part of 'Traditional knowledge' as Ancestral wisdom, but also integrated into Indigenous ways of thinking and knowing today.*

> *The connection is that STEM is the building a block of ancient Aboriginal culture. Aboriginal culture was able to use science to live off the land, collect natural medicines and protect native animals. Aboriginal culture was able to create technology like hunting tools, weapons, clothing and instruments. Aboriginal culture was able to thrive through environmental engineering. Aboriginal culture was able to use maths to ensure that no natural resource was wasted or overused.*

> *Our culture is built on mathematical genius (like the kinship system) and feats of engineering and science. We are the original STEM culture, we just never needed to or need to separate it from culture and Country and life.*

> *STEM has some form of relation to every culture. Torres Strait Islanders have scientific knowledge spanning tens of thousands of years. Technological and engineering skills were developed and refined in order to craft the tools and vehicles to master their surroundings. Mathematics was employed through the charting of distances to navigate in relation to the constellations in the night sky.*

> *Aboriginal and Torres Strait Islander sciences have incorporated, but not been limited to, sophisticated knowledges and practices pertaining to seasons and meteorology; astrology and astronomy; bush food, medicine and healing.*

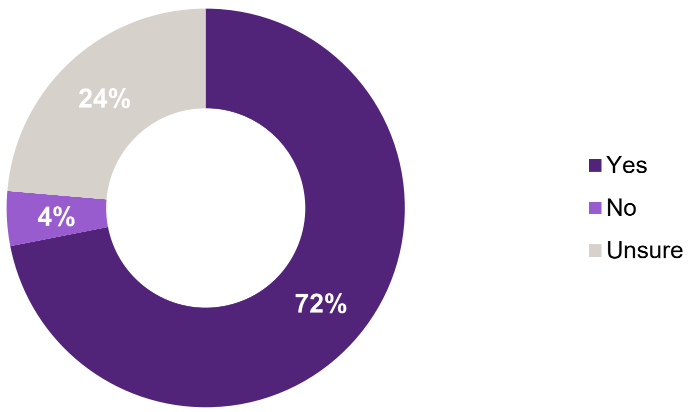
Justifications provided by participants who did not see a connection included: (i) the lack of building the connections between culture and STEM; (ii) experiences in colonial education systems; and (iii) still building awareness and understanding of STEM. One participant shared a potential solution to support how to build the connection:

> *I think if it was framed more as what it can do (e.g., real-world problem solving, innovation) rather than what it is (S.T.E.M) that would help.*

STEM in everyday life

Of the 203 participants who responded to the item 'I use STEM in everyday life…', 146 (71.9%) agreed that they used aspects of STEM in their everyday life. Common examples of how these people are using STEM in their everyday life included: "Everywhere you look, you can find STEM. Wherever there are questions to be asked and problems to solve, STEM is there too"; "Using modern electronics daily. Encouraging young people to become aware of environment and life"; and "caring for Country". However, there were also nine participants (4.4%) who reported that they did not use STEM in their everyday life, with an additional 48 (23.6%) unsure if they did (see **Figure 21**). These participants often reported "I don't personally see myself using science everyday", "retired", "I'm a sahm (stay at home mum)" as the reasons behind not using STEM in their everyday lives. While "I'm learning what it is", "I'd say I do but don't recognise it much", and "Whilst I use technology, I am not directly involved in one of the STEM industries" were reasons provided by participants who were unsure.

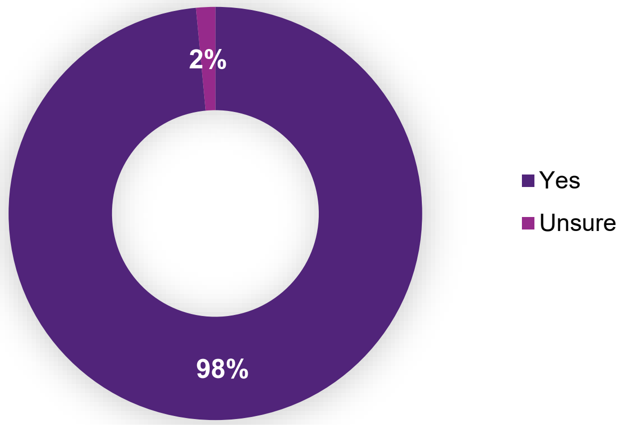
Figure 21
Participant Responses to Whether They use STEM in Everyday Life



Importance of Indigenous people being represented in STEM fields

Of the 204 responses given, overwhelmingly participants indicated the importance of Indigenous people being represented in STEM fields (201/204) (see **Figure 22**).

Figure 22
Participant Responses to Whether it is Important for Indigenous People to be Represented in STEM Fields



Some participants shared:

> *Yes 100% I believe it's important Indigenous peoples are represented in STEM fields. It's vitally important that we break down the barriers to ensure Indigenous knowledges of STEM are promoted and valued as much as 21st century western STEM.*
>
> *Yes, very important. I feel that the general Australian public are not aware of the STEM that has been used in our societies prior to the arrival of the first fleet. Yes, First Nations people were able to successfully manage the land for thousands of years with resources directly from the land. They have a wealth of scientific knowledge that others could learn from.*
>
> *Yes, very important as STEM will become increasingly more important in the future and Indigenous people need to be able to be involved and represented to make decisions in areas relating to STEM that affect them and their communities.*
>
> *Absolutely. Our knowledge lies at the core of a sustainable and equitable future in so called Australia. Indigenous people deserve to be valued in all aspects of society, especially STEM. Indigenous knowledge is historically oppressed, misunderstood, and devalued.*
>
> *Further representation in STEM would mean ongoing justice for Indigenous people. We have amongst us some brilliant minds which need to be raised to their full potential. This requires a lot of equitable and self-determined support.*
>
> *It's also good for our jarjum to see people like themselves in these positions - being able to see it, makes it even more possible!*

Are Indigenous peoples supported to pursue STEM?

Participants were asked if they thought Indigenous peoples are supported to pursue STEM. Approximately one third of participants believed that Indigenous peoples are supported to pursue STEM (64/204 responses, 31.37%) (see **Figure 23**). They indicated that this seems to be something that has happened in more recent years and stated:

> *I do believe in recent times there has been a concerted effort to promote Indigenous peoples in STEM. The activities I have been involved in at (redacted) have shown this. I just wish this effort was put in 20 years ago!!!*

A similar portion of participants also indicated that they believe that Indigenous people are not supported to pursue STEM (56/204 responses, 27.45%). Some participants offered the following statements:

> *Indigenous people are greatly underrepresented in STEM and this is even more so for Indigenous girls and women in STEM.*

> *I think there are narrow opportunities to promote STEM to mob - I have seen lots of corporate opportunities for mob students studying STEM at university, but this often seemed to be driven by RAP quotas for graduate programs opposed to the value add that Indigenous peoples are in this field.*

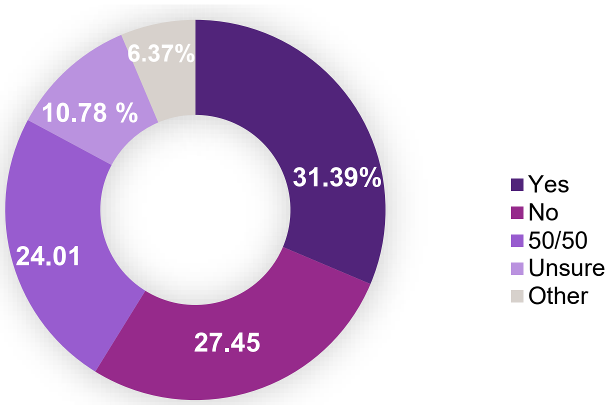
There were also some participants who were not a confirmed yes or no; their result reflected a 50/50 response which was dependent on circumstance (49/204 responses, 24.01%):

> *It depends on the circumstances and where. Currently at the university I attend I feel quite supported and encouraged but in other areas or places where this support isn't as easily accessible it's a lot harder.*

> *To a small extent, there are several opportunities in school that encourage it (although some not anymore (ASSETS)) however into adult life there are not many opportunities or support systems to encourage this.*

Figure 23

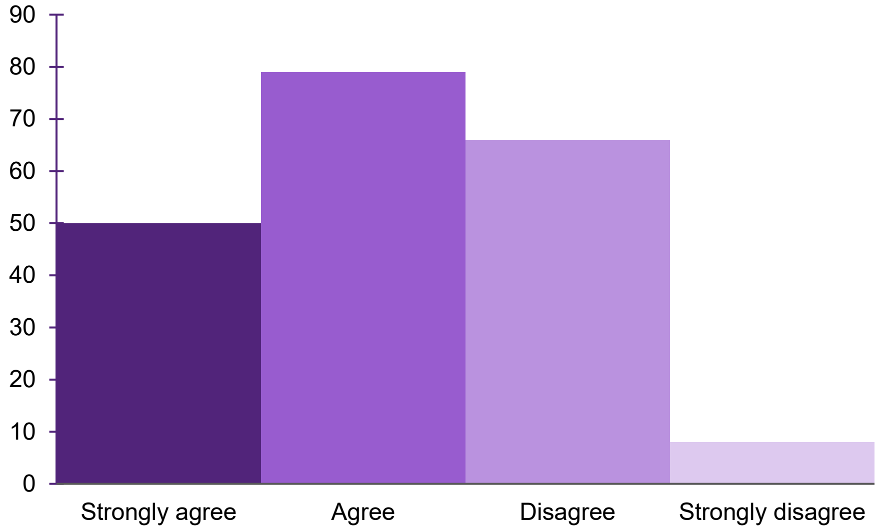
Participant Responses to the Question 'Are Indigenous peoples Supported to Pursue STEM?'



Pursuing a STEM career

In total, 203 participants provided a response to the item, 'I was (or currently am) interested in pursuing a STEM career'. **Figure 24** presents the spread of results from strongly agree to strongly disagree. Overall participants either strongly agreed (24.6%) or agreed (38.9%) that they were currently (or had been) interested in pursuing a STEM career.

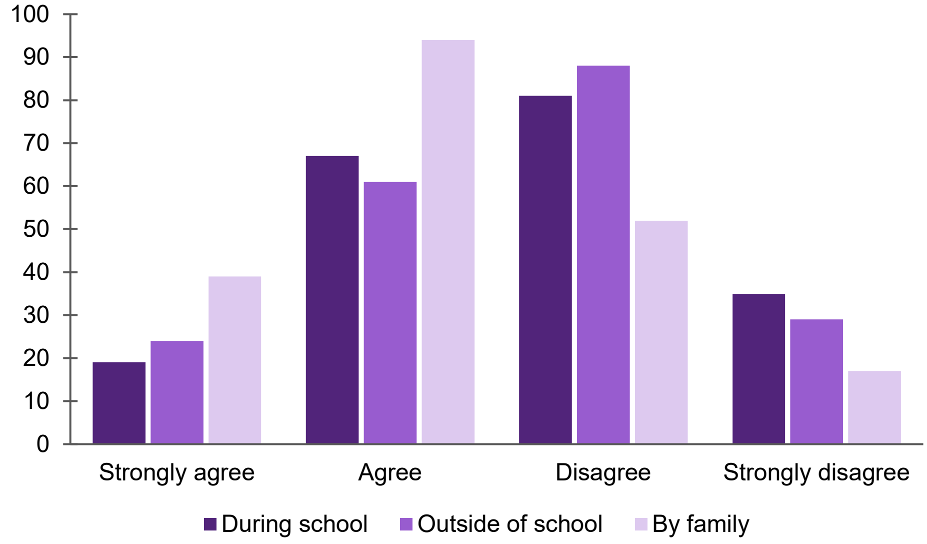
Figure 24
Participant Levels of Agreement in Response to Their Interest in Pursuing a STEM Career



My interest in STEM was supported during school, outside of school, or by my family

Participants were asked to indicate if their interest was supported during school, in outside school programs, and by their family. In total, 202 participants responded to these three items (see **Figure 25**). From the responses given it is evident that STEM was supported more by family than by school or outside school programs.

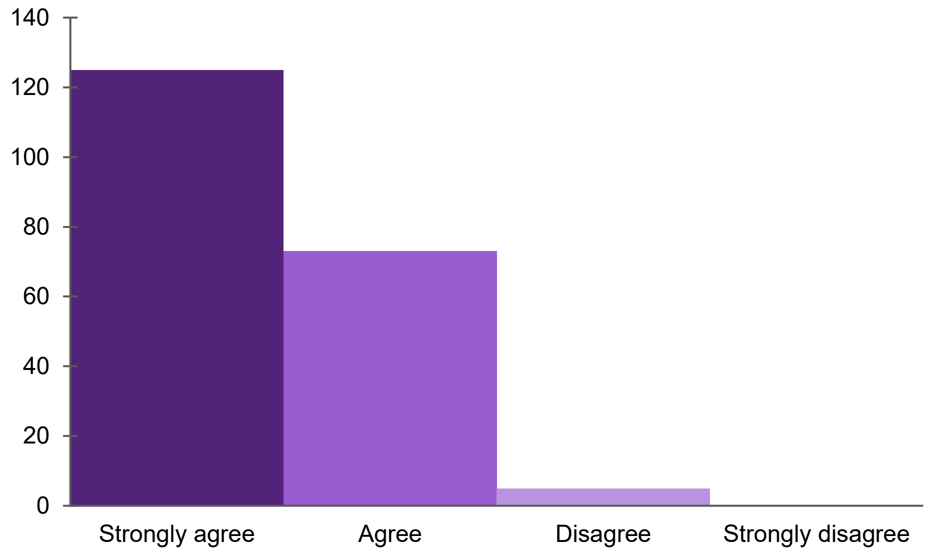
Figure 25
Participant Levels of Agreement to Whether Their Interest in STEM was Supported (a) During School, (b) Outside of School, or (c) by Family



STEM can benefit my community

In total, 203 participants responded to the question 'STEM can benefit my community'. **Figure 26** displays the spread of responses from strongly agree to strongly disagree. As it can be seen majority of people either strongly agreed or agreed that STEM can be a benefit for their community.

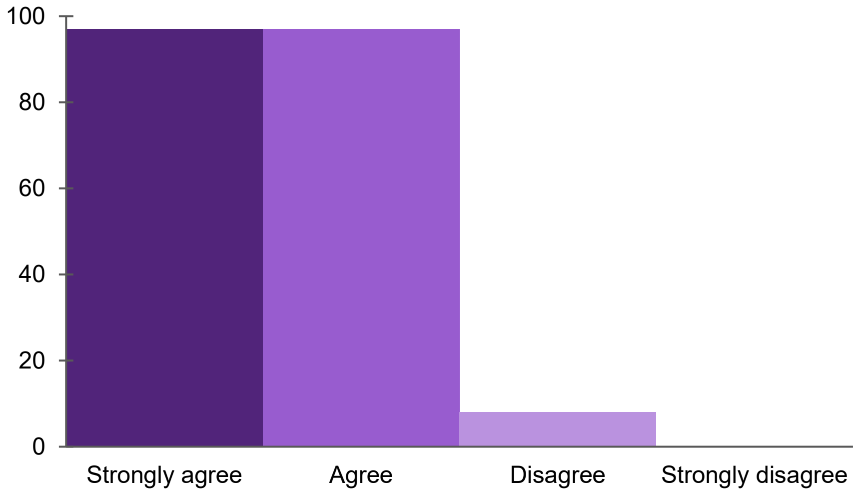
Figure 26
Participants Agreement to the Statement 'STEM can Benefit my Community'.



Studying or choosing a career/job in STEM is a way to give back to my community

In total 202 participants responded to the item 'studying or choosing a career/job in STEM is a way to give back to my community'. Overwhelmingly, participants indicated that they either strongly agreed or agreed to that statement (see **Figure 27**). Few participants disagreed with this statement.

Figure 27
Participant Agreement to the Statement That Studying or Choosing a Career/job in STEM is a way to Give Back to Their Community



Looking to the future:

How can STEM support future generations?

There were two ways in which participants responded to the question 'How can STEM support future generations?': (i) suggestions for improvements to how STEM could support future generations; and (ii) links to STEM innovations to support future generations. In total, 192 participants provided a response to the question. Each response was only categorised to one of the themes identified. After final analysis there were 117 responses aligned with innovations, 57 responses indicating improvements. Participants also indicated they were unsure (6) or provided responses that did not align to the item (12). **Table 12** displays the analysis for the questions under these categories.

Table 12
Themes From Participant Responses to 'How Can STEM Support Future Generations?'

Theme	Sub-themes	Example responses
Innovations (117)	Opportunities for new careers and employment, caring for Country, sustainable practices, improving quality of life	STEM provides… "career opportunities and a way of taking care of country and place for future generations."
Improvements (57)	Acknowledging Indigenous knowledges, Indigenous representation, education including STEM, advertising STEM and what it is	"First, the discourse around STEM needs to shift to include more Indigenous representations."
		"Expose our kids at an early age to stem... have the yarn and connect our ways of knowing and doing."
		"Getting the word out there about STEM."

What challenges do you see future generations may have with accessing a STEM career?

To support future generations access to a STEM career, it was important to identify the challenges from the survey participants. This was an open-ended qualitative question where thematic analysis was undertaken. Some participants provided more than one response; for these cases, each example provided was coded individually. In total, there were 280 different responses were provided from 193 participants (11 participants did not provide a response). The following five themes emerged from the data as presented in **Table 13**.

Table 13
Challenges for Future Generations Accessing STEM Careers

Theme	Sub-themes	Example responses
Barriers (57)	Racism, locality, SES discrimination, low expectations	"Systematic racism and lack of equal opportunity historically". "Many opportunities seem to be limited to capital cities which can limit how mob might be able to engage if they don't wish to leave their home community." "Systemic issues…. having disabilities and being culturally unsafe in corporate spaces and schools needs to be prioritised to the same amount as sex and ethnicity." "The technological divide is still a major issue for all Australians in rural and remote areas. Sometimes these fields are really targeted at the elite white of society which can make for a systematically racially challenging environment."
Individual (37)	Support, opportunities, confidence	"There are so many barriers…. Additional support and encouragement all through high school as well..." "No support provided & ongoing opportunities."
Financial implication (36)	Affordability, cost of education, lack of funding	"Financial challenges, with the increase in costs and the significant financial expenses that come with study." "I believe funding will be the biggest roadblock for future generations accessing the educational requirements for a STEM career."
Awareness about STEM (30)	Understanding STEM	"Not knowing enough about STEM…" "Wrapping their heads around the whole idea of STEM. It comes off as if you need to have a certain grade, that it is too far and high of a goal to reach which only pushes people away…"
Education (27)	Education pathways, resources in school	"Equal education."

Theme	Sub-themes	Example responses
		"Education barriers still exist and can be a barrier to accessing a STEM career. STEM is already a popular field of study and is likely to become more popular in the future. The courses may become more competitive." "Also I feel that the current education system does not incorporate our traditional ways of learning. I know that I struggled in school and didn't do well in my HSC. If it wasn't for educational pathways and financial support I wouldn't have furthered my education."
Future job (26)	Competitive job market, lack of job opportunities, technology replacing current jobs	"Globalisation, while they (STEM) are a universal skill sets that also increases competition for roles." "I think the biggest factor that may be faced by future generations may be… and the competitiveness of the industry." "Elimination of rare earth minerals, competition over remaining resources, AI takeover of STEM initiatives…"
Access (20)	Access to education, programs, funding	"Access to high quality education." "No access to STEM education from an early age." "Most of STEM are largely practical and having access to a place to participate in these practical activities will be difficult especially for those in rural areas or other areas where access to the university is more difficult. Even with the option to take a course externally, students may still find it difficult to study have access to some aspects of a STEM career."
Recognition of Indigenous peoples and knowledges (17)	Acknowledging and valuing Indigenous knowledges, Representation of Indigenous people, cultural awareness, alignment to country	"… with stem and aligning that to our responsibility as Aboriginal peoples to care for country and give back to our community." "Institutional racism and a dominance of white patriarchal systems that push mob down with layered policies and processes that don't value Indigenous ways of knowing and being." "More role models showcased of mob in STEM so kids can see this as something achievable."

Theme	Sub-themes	Example responses
		"… you can't be what you can't see… STEM careers do not centre community and same priorities mob have."
Other/Unsure (15)	The responses given do not align with a theme or participants were unsure.	
No challenges (7)	Participants stated there were no challenges for future generations.	

In reimagining education, how can schools better support a start in STEM for Aboriginal and Torres Strait Islander children?

The final question of the survey focused on reimaging the role of education in supporting a better start in STEM for Aboriginal and Torres Strait Islander children. In total, 196 participants provided responses to this question. The responses were coded in relation to idea given by participants which in some cases participants gave up to three different ideas in relation to reimagining education. Each of these ideas have been counted once and then re-coded into themes. In total, 267 ideas were coded, with four major themes reported. The remaining nine responses were unclear or the participant indicated they were unsure. The major themes that emerged from the analysis of data are presented in **Table 14**.

Table 14
Thematic Analysis to Question 'How Can Schools Better Support a Start in STEM for Aboriginal and Torres Strait Islander Children?'

Thematic analysis reimaging STEM education	Number of responses
Changing schooling by: introducing STEM education early; providing practical learning experiences; teaching STEM in schools; building parent partnerships; and creating pathways for later education	144
Connections to Indigenous knowledges, peoples, and Country	92
Increasing STEM awareness	22
Building student confidence	14

Many participants indicated they felt that STEM need to be introduced early in education and continued throughout schooling. It was apparent that participants felt that more time was needed to be given to STEM learning in schools, providing an education beyond basic skills (e.g., literacy). Practical learning experiences and other pedagogies that included hands-on approaches were also seen as ways to positively support Indigenous students. Participants also raised the importance of creating safe learning environments and having school leaders who come from a strengths-based approach to education. Access to programs, pathways to universities, and scholarships were identified as ways to continue to support Indigenous students in accessing STEM in the future.

Connections to Indigenous knowledges, peoples and Country was raised by many participants and often woven into responses about changes needed in schooling. Connecting how STEM relates to Indigenous knowledges was a central to valuing and respecting Indigenous culture. Some participants indicated that there is a need for a standalone Indigenous sciences subject offered at school, or the need to have classes that focus on Indigenous culture and knowledges. There was emphasis on connections to Country, caring for the land and sea, as well as totems. In reimagining education, participants stressed the importance of having Aboriginal and Torres Strait Islander educators in schools, showing connections to ways of being and doing and providing opportunities to learning on Country.

The theme of raising STEM awareness was also apparent in the participant responses. Young people needed to be made aware of what STEM involves and how it can benefit their lives and some participants indicated that young people may miss out opportunities because of a lack of awareness. To raise awareness of STEM, it is essential that this is across all members of community, parents, and young people. Suggested ideas to raise awareness included: holding information sessions with parents; working with Aboriginal services who can learn about STEM and share that information with the people they work with; providing careers expos; flyers sent home from school; and establishing youth groups at the Police-Citizens Youth Clubs.

Finally, participants shared that there is a need to encourage and support Indigenous students to build their confidence to pursue STEM. It is acknowledged that this theme has overlap with 'changes in schooling', where some participants indicated the important role educators play in this space. However, despite this overlap, it was decided to highlight 'building student confidence' as a standalone theme.

The following are some quotes from the participants sharing how they are reimaging STEM education for future generations:

> *Firstly, having education in relation to Aboriginal and Indigenous culture and being inclusive in school.*
>
> *My dream is one blackfella per school employed in some capacity as a cultural advisor. I do it all the time and don't get paid for it but perhaps a teacher who loves mob who can give kids the passion needed to pursue STEM.*
>
> *Ensure Indigenous children actually understands what STEM is and that it's not just potential career options but something that we already use in our everyday lives.*
>
> *Letting people see that this is an achievable career to have.*
>
> *Having discussions with MOB about STEM and what it involves and how you can be involved.*
>
> *First Nations people coming into school and talking about how they have stated a career in STEM - Hope and mentorship.*
>
> *Informing parents and students what STEM is and how it's connected to our culture and ways of working. By conducting incursions (having community involved) and excursions out on country to see First Nations organisations that link to STEM.*
>
> *Inclusive and diverse learning approaches, not all children learn in the same way. Learning that is provided on country, showing connections to traditional ways of life would be great.*
>
> *Understand and promoting non university acquired knowledge systems and cultural education in stem fields as being worthy. Providing accessible opportunities regardless of location or social status. Giving insight and examples to break down what STEM is throughout life and work in general so it's not so intimidating or foreign.*
>
> *Build their confidence. Treat them equally and protect them from others bias, judgement of racist comments. Educate others in knowing how to support Indigenous children. Promote a zero tolerance to bullying and racism. Provide education support and resources for those in isolated communities.*
>
> *Supported pathways into university, showing examples of how Indigenous knowledges translate to this new concept of STEM, encouraging them to experiment and listen to Country and be curious about the world.*
>
> *Connect culture to STEM regularly and in meaningful ways. I heard that some schools in regional and remote Australia do not provide specialist maths or some of the sciences in senior high school - so either the kids do not study it or they have to study it online, which is particularly challenging.*

Zoom out to consider the issues and complexities that the world will face in 20-30 years' time, as current students will be tasked with solving these problems. Reconsider how Indigenous knowledges have always innovating, we are responsive and adaptive and have much to offer the future of STEM to sustain people and Country into deep time.

Finding genuine interest in students and engaging mob with autonomy to choose stem related programs that reflect their interests.

Get in an elder who knows what they are talking about regarding land and Country.

Study 3: Podcast

The *Big Mob: STEM it Up* project interviews/yarns were conducted with 15 Indigenous people currently engaged in professional roles in STEM fields. Fourteen of these interviews have been made into podcasts (Shay, 2023). Participants were asked 17 questions regarding their experiences in their STEM education and careers. Of the 15 participants interviewed, seven were female and eight were male. The participants came from different fields of STEM. In total, 53.3% were from science, 26.6% were from technology, 13.3% were from engineering, and 6.6% were from mathematics. The 15 Indigenous participants represented 20 Aboriginal and Torres Strait Islander mobs. Of these representations, two were Torres Strait Islander people. Participants resided across different parts of Australia, with eight participants from Queensland, five from Western Australia, one from New South Wales, and one from Victoria.

Representation

There is great diversity within Aboriginal and Torres Strait Islander peoples, exemplified by over 250 different language groups spread across Australia (AIATSIS, n.d.). The cohort represents a portion of this diversity. **Table 15** captures the different mobs of interview participants:

Table 15
Mobs of Interview Participants

Mob		
▪ Ballardong Noongar	▪ Kamilaroi	▪ Quandamooka
▪ Banjima	▪ Mandandanji	▪ Trawlwoolway Pakana
▪ Bardi Jawi	▪ Minang	▪ Wakka Wakka
▪ Birri Gubba	▪ Ngarluma	▪ Warangu
▪ Erub	▪ Ngemba Wailwan	▪ Wiradjuri
▪ Gangulu	▪ Nyamal	▪ Yuggera
▪ Goreng Goreng	▪ Nyiyaparli	

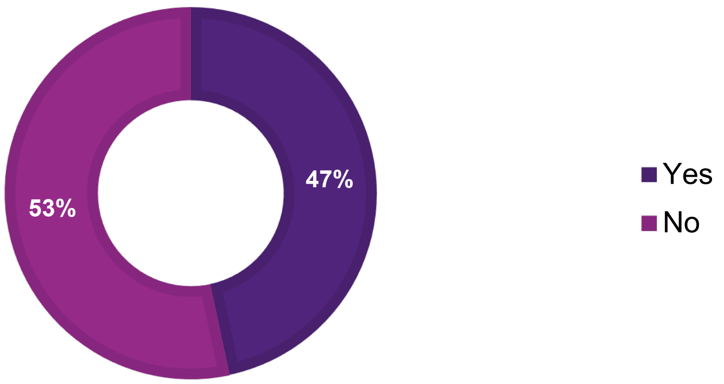
The professional roles of the participants were as diverse as who their mob was. **Table 16** demonstrates the diverse roles participants hold within STEM:

Table 16
Professional Roles of Interview Participants

Science	Technology	Engineering	Mathematics
▪ Nyiyaparli Ranger ▪ Ophthalmologist ▪ Regional Ecologist Ranger ▪ Ranger Program Project Officer ▪ Chief Executive Officer ▪ Bio-Cultural Science Educator ▪ Researcher/teacher ▪ Graduate	▪ Senior Product Technologist ▪ Chief Drone Pilot ▪ Managing Director ▪ Researcher/teacher	▪ Civil Engineering Operations and Development Manager ▪ Senior Systems Engineer	▪ Executive Director

Figure 28 highlights how many of the participants were in an identified role.

Figure 28
Percentage of Participants Who Were in an Identified Role



How mob saw STEM used in their families and communities

Family and kinship connections are important parts of Aboriginal and Torres Strait Islander identity (Behrendt, 2006). Connections to community are also an important source of resilience for Indigenous peoples (Dudgeon et al., 2022). Through this lens, the question was asked how participants viewed STEM being used in their families and their communities. Two codes clearly emerged from the NVivo analysis: family connections and knowledge sharing.

The code of family connections was evident from many of the participants providing in-depth stories of interactions with their family. This was often where participants had their first interactions with STEM. Such family connections were highlighted by Josh, who shared the following: “So STEM in my family really originated from my Aunty, so she's an accountant... she was the first in my family to go to uni, which really broke down the barriers for the cousins and I to go.” This ‘first in family’ aspect was also conveyed by Bonny, who was the first person in her family to go to university. The issue for Aboriginal and Torres Strait Islander peoples being the first in their families to go to university has been acknowledged as an area that all Australian universities need to address (Behrendt et al., 2012).

Not all the participants entered their STEM fields through a university pathway. Corey spoke about his introduction to STEM by relating the connection he had with his grandfather: “When I was younger, you know, I spent a lot of time with my grandfather... He's a Kamilaroi man... he knew a lot about wildlife and animals. And I kind of inherited that from him”. There is knowledge being passed from one generation to another around knowledge of wildlife and animals.

This connection to knowledge sharing described by Corey was the second major code from the question of how mob saw STEM used in their communities. Scientists in Australia are now starting to recognise the importance of Indigenous knowledges in caring for our environment (Macdonald et al., 2022). Coen also shared his experiences of knowledge sharing between his family and community: “A lot of the stories and knowledge that like my community have are from scientific practices, and the definitions of what science is are not limited just to Western culture.” This view of recognising the importance of Indigenous knowledges is reflected by the CSIRO (n.d.):

> *We are working with Indigenous collaborators to support the strengthening of Indigenous knowledge and knowledge systems so we are all able to weave and share knowledge in ways that recognise the integrity, validity and context of each different knowledge system. (para. 1)*

Susan provided a powerful connection between her family connections and how Indigenous knowledge was being used by her family and in her community:

> *Dad would go down to the river most mornings and bring us a fish from the fish traps. I always thought that he went down to the traps and caught them himself. But years later he told me that he sat with the old men for a yarn and the young fullas would bring up a fish for him. So that's one way that we... we've actually used our technologies.*

What is evident from the findings is that there is diversity among Aboriginal and Torres Strait Islander peoples on how they view STEM being used in their families and their communities. However, the codes of family influence and knowledge sharing clearly emerged as being significant in shaping the perspectives and motivations of Indigenous people who have taken STEM as a career path.

Highlights of STEM education

Each of the 15 participants were asked the following question: What have been the highlights of your STEM education? Three codes clearly emerged in analysing responses to this question: sense of achievement/success; relationships; and hands-on practical experiences.

For many of the participants, the highlight of their STEM education was the sense of achievement. Carol-Anne expressed this sense of achievement:

> *Some of my highlights was just to grow up and achieve something. I didn't think I was gonna be a Ranger looking after my country. And also being a director for my company for*

> *our PBC Karlka Nyiyaparli. So, yeah, it's two big roles and I'm very proud to be where I am today to take on that challenge.*

Noel linked the concept of being the "first in family" (Behrendt et al., 2012, p. 22) to completing school as an achievement when he said, "[I was] the first in the family to graduate high school". During the interview with Noel, it was evident that he was proud of his achievement.

Relationships was another code to emerge from the analysis where many of the participants mentioned that relationships were the highlight of their STEM education. Relationality underpins Indigenous ways of knowing, being, and doing. "Aboriginal epistemological systems both intuitively and explicitly recognized the interconnectedness of all things, and this symbiotic relationship helped to create a harmonious coexistence with all living things and the environment" (Morgan, 2018, p. 113). The responses from participants were diverse, but the importance of relationships as a highlight of their STEM education was clear from the findings.

Mel articulated how relationships were a highlight of her STEM education: "I'd say that would probably be it. And that broader community, from both the Indigenous networks that I made throughout university, but even just the normal connections. Like I still have very close friendship group from there". Similar to Mel's experience at university, Josh spoke about his experience at university and the importance of relationships in his STEM education: "My highlights include obviously playing sport at uni... was really fun. Going to King's College was... was really awesome. The friends that I made along the way".

The final code to emerge from the question regarding the participant's highlights of their STEM education was the practical/hands-on aspect of their experience. Bonny spoke about her love of the hands-on experiences of her STEM education: "I love being in the labs and learning kind of hands on. In uni, I did quite a few diverse topics - so like food engineering, nutrition, food chemistry, biochemistry, and microbiology. Just being able to do all those really different things and have those really different experiences, I really enjoyed." Similarly, Marlee shared how important the practical aspects of her university degree were:

> *I understand the theoretical side of things was important, but I'm a big practical person. And... and all the practical experiences I learnt in my university degree were great, like the field trips - we had like, you know, week-long field trips out, you know, doing fish surveys and seagrass surveys and things like that.*

While acknowledging the theoretical side of STEM was important, the highlights for Bonny and Marlee were the practical, hands-on experiences. Marlee went further, adding the importance of field trips and being out of the classroom.

It is clear from the findings that there were diverse highlights of Indigenous peoples' experiences with their STEM education. All of the highlights from the participants were positive experiences. Overall, participants were proud of their achievements within their STEM education and were keen to have their stories shared with their families and communities via the podcasts.

Inspirations and motivations

Regarding their STEM careers, participants were asked who and what inspired them in their career journey. Eight of the participants mentioned that it was family that inspired them in their STEM career, making it the strongest code to emerge from the data. Family is a fundamental part of Aboriginal and Torres Strait Islander culture. Family provides connection to identity, culture, spirituality, community, and Country (Ristevski et al., 2020). It was identified by most of the participants as a motivator for them in their STEM career. Torres spoke about how certain family members have inspired him:

Another man was old man and granddad George Mye. He also was a fantastic leader, internationally, around our treaty called the Torres Strait treaty to continue our cultural practices of trade, family and kinship with coastal villages along Papa New Guinea… So, so many people along the journey that help us in different ways that can inspire us.

Kris also shared a powerful story of the challenges his family had gone through, and how that had motivated and inspired him:

It's a question I'm asked a lot and I've thought on it a lot. I... I think... and no one individual inspired me. I mean, some people will mention one person or another. For me, it was more the story of survival and the story around taking the opportunities made to each generation before me and... and building on that to make the next generation's story a better one. And the story that was always in my family was the story around my Warangul great-grandmother, who was... who was forcibly brought down from Bowen and then processed through Myora Mission on Straddie and... and then ended up marrying another Aboriginal - well, marrying an Aboriginal man who wasn't under the Act. And... and it was her story of survival and then her ability to have her children and not have any of them taken away, thank the Lord. And then so, you know, then my Nana successfully having her kids. And then, of course, my mother being successful. So it was more a story of... of looking at those who came before me and the successes that they built on to make it better for the next generation. So it's not one person, but I think if I... if I did have to name someone, it would have to be the story of my great-grandmother. And, although I never met her - she passed when my Nana was only 12 - but it was always that story and that... that family, that oral history of where she had come from and how we'd been able to sort of pick ourselves up from the nasty mission days.

Mel also shared how the support of her family motivated her to go to university:

Interesting enough, it wasn't anyone who you would think of as being STEM or literally career minded, but my grandparents. I... little bit... probably too much information for the group… came home pregnant at 17. And the only thing my grandparents asked me was to make sure that I finish my university education. No ifs, no buts. No, you know, nothing to say that you're a bad person or anything like that. And supported me the entire way. So yeah, they were there. And, yeah, it sort of made me realise you could do that with that support of that family and that community around you.

The second code to emerge was the importance of role models who motivated and inspired the participants in their STEM careers. Six of the participants mentioned role models or mentors having had a positive influence on their STEM career. A 2021 CSIRO *Indigenous STEM Education Project* report highlighted the importance of role models for engaging Aboriginal and Torres Strait Islander young people in STEM (Walker & Banks, 2021). During his podcast interview, Andrew spoke about how mentors have inspired him in his career: “Some mentors that I've worked with over the past few years. And a couple of them have been through... I've met through running our Indigenous mapping workshop.” Josh also spoke about the importance of mentors in motivating him throughout his STEM career: “So, in my career journey, I've had a lot of good, good mentors, great bosses over throughout my career.” Theresa spoke about the importance of role models in her STEM career, and how it was often more than one person:

I guess I've had... I've had a number of people that I've looked up to. I wouldn't say there's one particular person who's like an in... you know, my inspiration or whatever. I just sort of pick it up from a whole heap of people.

It was evident from the interviews that family was a strong motivator for Indigenous peoples to pursue STEM, and that role models and mentors play an important role in supporting Indigenous peoples across their STEM journeys and careers.

Barriers to thriving in STEM

According to the 2020 *Australia's STEM Workforce* report (Australian Government, 2020a), just one in 200 Aboriginal or Torres Strait Islander people of working age have a STEM degree, compared with one in 20 non-Indigenous people. Given this statistic, the question was posed to participants: What barriers did you face as you pursued STEM? While there was a large range of responses, two codes were identified from the analysis: isolation and educational experiences.

The isolation code emerged from in-depth experiences shared by participants. As the data shows how few Indigenous people are undertaking STEM roles, this finding is unsurprising. For example, Bonny spoke about her experience of being the only Aboriginal person in her course. Bonny said: "[B]eing the only Indigenous person in my course and kind of in some spaces at university was quite isolating. So, yeah, just... just being by myself and not having that community support was challenging at times as well." It was even more challenging for Bonny, because she was away from home to pursue her STEM studies in Melbourne. Susan also spoke about the sense of isolation that she feels within her STEM career: "The most important barrier is that there are no other people that I work with." However, Susan countered this barrier from a position of strength when she said: "[There is a] myth that there are no other Aboriginal and Torres Strait Islander people doing STEM - particularly technology and computer science - there are many of us out there. I've just been involved in setting up the National Indigenous STEM Professional Network." Another factor in the isolation code that was identified by participants was that they were the only female Indigenous people within their STEM career. This was a barrier that Theresa and Mel both faced.

Marlee spoke implicitly about the negative effects of isolation that were barriers for her pathway into STEM:

> *I think that that academic barrier was really difficult for the first part. And then after that when I got into the industry, also partly at university as well, the... I suppose, the barriers that were there just to do with, I suppose, racism were really difficult - like just being surrounded by people that had no understanding.*

Here, Marlee mentions dealing with racism, both at university and in her workplace. Marlee is not alone with her experiences of dealing with racism. In Australia, racism is an ongoing issue and it has negative effects on Aboriginal and Torres Strait Islander peoples' lives. It has been reported that 60% of Aboriginal and Torres Strait Islander people have experienced racism (Reconciliation Australia, 2022). Racism has surfaced across this data in investigating Indigenous participation in STEM.

In the above quote, Marlee mentions experiencing an "academic barrier" in pursuing STEM. A negative educational experience was the other code that emerged from the analysis. This code was multi-faceted. For some of the participants, their negative educational experience came from their low self-esteem of their own abilities. Grady shared the following:

> *Confidence was definitely a big one. Getting a good education can be difficult and there are a lot of barriers that, really, they can get inside your head and push you away. I used to be quite afraid of the physics of it. I would sit down and try maths and there wasn't a lot of confidence. And these started to feel like a lot of barriers.*

Theresa also shared her lack of confidence as a barrier she faced in pursuing STEM:

> *I think that obviously the engaging... well, I'll take it back. So, I guess, one of the biggest barriers was learning, I guess, at university. Everyone, I guess, always thinks that I'm this crazy smart person, but I'm actually not. I did terrible at high school and only got into university through an alternate entry program. Otherwise I didn't have the score to get in. So I think that I've always been at a... not a disadvantage, but I've always been one step*

behind everyone else in terms of, like, learning and being able to understand key concepts and stuff that was... that took me a long time. And I had to work really hard at it.

For Marlee, the negative educational experience came from dealing with racism. And for others, it came from the low expectations that their teachers had on them. Torres spoke about how his teachers had "low expectations around thinking of our intellectual capability". The findings indicate that the 15 Indigenous participants experienced barriers in pursuing a career in STEM. What is clear is that, despite these significant challenges, all 15 participants have successful STEM careers. The two codes to emerge from the analysis in understanding barriers to Indigenous people thriving in STEM – isolation and educational experiences – are interrelated and are connected to aspirations to have more Indigenous people enter STEM careers. However, there are limited policy interventions that might address both issues in a timely way. The *Closing the Gap* imperatives have shown very limited gains in educational outcomes (Australian Government, 2020b). These findings demonstrate the challenges in enacting institutional change and increasing Indigenous participation in STEM are bound with these broader goals of improving educational experiences and outcomes for Indigenous people.

STEM career highlights

Participants were asked the following question: What have been the highlights of your STEM career? The responses were varied and included interacting with Elders, graduating university, attending STEM orientations sessions, and establishing their own business. After analysing the responses, two recurring codes emerged: caring for Country and community.

Country is a central part of cultural identity for Aboriginal and Torres Strait Islander peoples. Country is at the centre of coming to understand relationality, as it is the thing that connects Indigenous peoples to their systems of knowing, being and doing (Tynan, 2021). Coen spoke about how being on Country was a highlight of his STEM career:

One of the biggest things is being out on... on country and engaging. But yeah, I've been privileged enough to go out and engage with mob on country, because that's just one... that's just something like, you know, we've got to do as black fellas is have that respect and go about it proper ways. And then seeing that good engagement, you know, as it's a bare minimum thing, but it was something I didn't realise that I'd missed through my whole undergrad, postgrad - I'd never seen good engagement.

Similarly, Marlee shared how, in her STEM role, the ways she is caring for Country have provided "massive highlights":

Just those moments where we find something that... what... you know, that the Rangers or Traditional Owners have been looking for or something that's significant to them. Like, every time we get a bilby on camera or a quoll on camera or just these, you know, significant animals, like they're... just especially in areas where we thought they were gone, because of cane toads or feral cats, and then seeing that they're still there and we still have hope and we could still do something - like they are the wins for me. Like that's just, yeah, a huge, huge win to me.

The reward of seeing that and being like that wetland is not going to get trampled by cattle anymore. This cultural place is going to re-establish and the natural vegetation is going to come back. The animals are going to be safe. Like we've got... we've got that place undercover, like, it's protected. And that's a huge highlight as well when things like that *happen and you can really genuinely have meaningful impact, I think. Like that's... that's massive highlights for me.*

The concept of community is fundamental to identity and concepts of self in Indigenous Australian cultures (Dudgeon et al., 2022). While community was mentioned by all participants throughout their interviews, there was a strong indication of ‘contributing to community’ that recurred across responses to this question. This sense of contributing to community as a STEM career highlight is explained by Grady:

> *Being able to pioneer the drone program. To be able to go out and actually sit in a classroom and teach people. To show my passion. To stand there, smile and be happy. To get questions that I want to answer. Those are the ones that have really stood out to me. And a lot of those other ones were great because I got to do, I got to build, I got to see, I got to do. But I didn't get to give back. Not in that same way. And so while they've been very important to me, a lot of these opportunities at Winyama - going out with the Rangers and doing training, developing new processes with the drones, testing new equipment - it's been amazing. A really, really great one for me was the Women's Fire Forum. It was about three years ago up in Broome. To see so many female Rangers was incredible. We had 50 or 60 of them in the one room.*

Another example of giving back to the community as a career highlight was shared by Torres:

> *So many different highlights along the way. But a lot of it is seeing the smiling faces in my community, you know, when you've done something really well, and they've come back to you and really appreciate, you know, the time and effort and energy, and want to keep continu[ing] to engage with you and work with you. You may be in a different role, but they'll still ask and find out and... and want to and continue to work with you and have build a good strong friendship and relationship. You know, there's heaps of these types of things that are out there that you can get different medals and things, but that's not... that's nice, but it's about, yeah, seeing that impact on the ground and have the communities to say, "Hey, all those trees that we planted all those years ago, Torres, with the kids. You should see it now. They're fruiting now. We're eating those things and now we're... we're planting some more and sharing those seeds with them". They're... that's what I love. And then another one - working on building capability around utilising digital technologies. They're out there doing all that digital artwork and they're... I inspired that with them, you know, and I went out there and took the... took the education program and opportunity to the remote area. And to see them branching out and setting up their own businesses now outside from the... their art centre on their own and building that. It's fantastic.*

Aspects of other codes were also present within Torres’s response. He noted how relationships, role models, and a sense of achievement were all important to his STEM career. Having the opportunity to share their STEM stories and highlights was a positive experience for the participants and the interviewer, and the passion and sense of pride when answering this question was evident across all 15 participants. This was particularly true for both Grady and Torres, as can be seen from their quotes above.

Indigenous initiatives: Success stories

The podcast questions were informed by strengths-based approaches; therefore, it was critical to identify where things have worked in order to know how to build on existing strengths (Shay & Oliver, 2021). This analysis reports on how Indigenous initiatives in STEM influenced participants’ careers. There were two codes that emerged from this analysis: Indigenous university initiatives and internships.

Attempts to increase Indigenous peoples' participation in university has been a policy goal for many years (Universities Australia, 2020). According to Universities Australia *Indigenous Strategy Annual Report* (2023), Indigenous student enrolment is 2.08%. Per this report, "most universities reported having formal, written strategies in place that included reference to a coordinated approach to Indigenous student recruitment across the institution" (Universities Australia, 2023, p. 8).

While there is still more to be done, the participants explained how some of the university initiatives had a positive influence on their STEM career. Theresa spoke about being accepted into university to undertake a STEM degree:

> *[B]eing... you know, coming from [removed for anonymity], I was the first person in my family to go to university. I relocated... when I relocated in... I was 18. From [removed for anonymity] to Brisbane, like, I just got on a plane and I moved. Like no one came down to help me... to help me set up anything. I had $1,500 to my name. Like I had nothing. So those scholarships really helped.*

Indigenous centres in universities are seen as key places to build a sense of connection and belonging for Indigenous students (Fredericks et al., 2022). Dedicated Indigenous university centres were a university initiative that had a positive influence on the STEM career of many participants, including Andrew who identified the Koori Centre at The University of Sydney as being important during his STEM studies. Kris also shared how he was supported through a university Indigenous centre:

> *At the University of Newcastle, the faculty supported the medical support unit for its Indigenous students. And that was... it was a very small space, but it was a space for us. And it supported that unit with the wages of a director and two support staff in there, as well as the Indigenous tuition scheme, which I... which I, you know, I did lean on getting through medical school. So that would be the main two areas.*

Indigenous internships were the second code identified in analysing how Indigenous initiatives positively influenced the STEM careers of participants. Internship opportunities allow people to practise and develop professional skills in a supervised work environment. A benefit of some internships is that they can also be paid positions. Bonny spoke about the opportunities that an Indigenous internship program offered her:

> *So I've participated in, like, Indigenous internship programs, which... gave me that work experience in the corporate space and in the work field. So really helped my kind of entry into it and, you know, helped with those breaking down the barriers and creating those pathways.*

An important point Bonny makes here is the capacity to "break down those barriers" that Indigenous people might face in the workplace. Bonny could see herself as a leader in breaking down barriers in the workplace and help create more opportunities for other Indigenous people entering the STEM field.

Marlee also spoke about the positive influence that an internship-type program had on her during her experience with CSIRO:

> *The Young Indigenous Women's STEM Academy, it's basically an initiative to support young Indigenous women who show, you know, high levels of academia or who are really driven in their studies. I think they get identified quite early - you know, in Year 7 or 8 and if they've got an interest in STEM. And the whole idea is they get supported all throughout their high school education and then on to their university education and then on to their*

> *work. So it's not like, okay, you've finished high school, we're just gonna, like, you know, shove you along. It's this whole support throughout your entire education and then on to work and... and they do... yeah, they do camps. They do awards. They offer support - heaps of different support. You get mentors, tutors, etc. So it's a really, really good program. CSIRO was in charge of an initiative... an initiative called ASSETS, which was for young Indigenous people in STEM. And they would take young Indigenous people who wanted to do STEM - I think they were Year 10 students that are taken on camps in different places around Australia. And I got to be a mentor on those trips. And I absolutely loved it. Yeah, I absolutely loved it.*

In another example from the CSIRO, Talia shared how a high school STEM initiative influenced her decision to pursue STEM:

> *I think it [the year 10 program] provided me like an understanding of like what occurs with people around the STEM area. You know, like what does a marine biologist do? What does an engineer do? What does an ecologist do? What does a programmer do.*

While there is still some way to go in increasing Indigenous participation in STEM, the evidence from the participants demonstrated that Indigenous initiatives have had a positive influence on them.

Mob recommendations for increasing Indigenous participation in STEM

Participants were asked the question: In the goal of increasing Indigenous peoples' participation in all areas of STEM, what are some recommendations you have to achieve this goal? There were varied responses from all participants. Some of the areas that participants spoke about were access to technology, education, and respect. However, after analysing the data from the interviews, two codes emerged: Indigenous knowledges and engagement.

Indigenous knowledges are a critical aspect when working towards increasing Indigenous participation in STEM. Indigenous knowledges are a large body of knowledge systems which one comes to know (Martin, 2008). These knowledge systems are deeply connected to land, spirituality, community, and cultural identity. Coen's recommendation is for clearly embedding Indigenous knowledges into the STEM space at university. He said: "It needs to happen, and we've got to make it happen now. So, I think there's going to be a lot… a lot to watch in that space of… of actually creating an Indigenous research paradigm in science." Torres spoke passionately about how we can move forward in this space:

> *It's about our families and our communities that are along on the journey. It's about opening up to doing, to thinking about science in... in a different ways and how we incorporate thinking of science. It's like I was saying before, within our own cultural ecosystem, there's our kinship - our kinship to place, our stories that connect us to these places. You know, how we include Elders within, you know, our knowledge transfer. It's really about doing things a bit differently and opening up and listening to us and have and creating some space for us to have our own knowledge systems and ways of working within the... within the institutions. Doesn't have to be one being right and the other wrong. How do we strike a balance? And then I always think about if we want to see some change, we got to change, come to change and do things differently. So we can't be doing the same thing over and over and expecting to get a different result.*

Torres is making connections with families and communities in enabling this process. He is also putting a challenge out to institutions about creating space for meaningful collaborations with Indigenous knowledges in STEM. In recognising Aboriginal and Torres Strait Islander knowledges in STEM, the Australian Curriculum, Assessment and Reporting Authority (ACARA) supported the development of science elaborations within cross-curriculum priority areas. ACARA (n.d.) states:

> *The elaborations acknowledge that Aboriginal Peoples and Torres Strait Islander Peoples have worked scientifically for millennia and continue to contribute to contemporary science. They are scientifically rigorous, demonstrating how Indigenous history, culture, knowledge and understanding can be incorporated into teaching core scientific concepts.*

The second code identified in the analysis was engagement. Hunt (2013) defines effective engagement with Indigenous people in the following way:

> *Effective engagement is a sustained process that provides Indigenous people with the opportunity to actively participate in decision making from the earliest stage of defining the problem to be solved. Indigenous participation continues during the development of policies – and the programs and projects designed to implement them – and the evaluation of outcomes. (p. 3)*

During her interview, Theresa addressed the issue of engagement in depth:

> *I just think so much more could be done in even just offering resources or sending a career counsellor - or not... not a career counsellor - sending like someone from the university to help with, you know, when it comes time to picking senior school... senior school subjects and stuff. And being like, "Hey, have you thought about how this might impact if you want to go to university and this is where you want to end up?" Just having that dialogue open is really important, and having it like genuine, genuine conversations I think are really important.*

The issue of having to leave home to attend university to undertake their STEM studies was experienced by many of the participants, including Kris, Torres, Bonny, Marlee, and Theresa. Corey identified that engaging with Indigenous young people a lot earlier in their education was critical: “It's got to start with the ground up. It can't... you cannot start at 15 or 16 or uni and expect to make a massive impact. These kids are already on their journeys from age 12.” Mel reiterated Corey’s sentiments, saying:

> *For me, if we're starting at high school, we're too late. We've gotta start back at kindy, start back in playgroup, start back in community, in nursing mothers playgroup areas, and the things that are those building blocks of STEM are incorporated. That it's not something that's weird or, you know, only smart people do, or only white collar people in the city do. That it's there and it's just normalised, but from a very young age.*

The key recommendations to increase Indigenous peoples’ participation in STEM highlighted from the podcast participants included:

- Embedding Indigenous knowledges in all areas of STEM education.
- Providing effective engagement with Indigenous people and communities, especially from a young age.

References

Australian Curriculum, Assessment and Reporting Authority (ACARA). (n.d.). *Aboriginal and Torres Strait Islander histories and cultures*. Australian Curriculum. https://www.australiancurriculum.edu.au/f-10-curriculum/cross-curriculum-priorities/aboriginal-and-torres-strait-islander-histories-and-cultures/

Australian Government. (2020a). *2020 Australia's STEM workforce report*. https://www.chiefscientist.gov.au/news-and-media/2020-australias-stem-workforce-report

Australian Government. (2020b). *Closing the gap report 2020*. https://ctgreport.niaa.gov.au/sites/default/files/pdf/closing-the-gap-report-2020.pdf

Behrendt, L. (2006). The urban Aboriginal landscape. *E-Proceedings of 'Post-Suburban Sydney: The City in Transformation' Conference* (p.8). https://www.westernsydney.edu.au/__data/assets/pdf_file/0007/6928/Behrendt_Final.pdf

Behrendt, L. Y., Larkin, S., Griew, R., & Kelly, P. (2012). *Review of higher education access and outcomes for Aboriginal and Torres Strait Islander people: Final report*. Department of Education, Australian Government. https://www.education.gov.au/download/2658/review-higher-education-access-and-outcomes-aboriginal-and-torres-strait-islander-people/3703/document/pdf

CSIRO. (n.d). *Indigenous knowledge*. https://www.csiro.au/en/research/indigenous-science/indigenous-knowledge

Dudgeon P, Bray A, Blustein S, Calma T, McPhee R, Ring I, & Clarke R. (2022). *Connection to community*. Indigenous Mental Health and Suicide Prevention Clearinghouse, Australian Government. https://www.indigenousmhspc.gov.au/getattachment/13b502f3-32a7-4dff-82ea-25c353bc45a3/dudgeon-et-al-2022-connection-to-community.pdf?v=1216

Fredericks, B., Barney, K., Bunda, T., Hausia, K., Martin, A., Elston, J., & Bernardino, B. (2023). The importance of Indigenous centres/units for Aboriginal and Torres Strait Islander students: Ensuring connection and belonging to support university completion. *Higher Education Research & Development*, DOI: 10.1080/07294360.2023.2258825

Hunt, J. (2013, October 4). *Engaging with Indigenous Australia – Exploring the conditions for effective relationships with Aboriginal and Torres Strait Islander communities,* (5). Closing the Gap Clearinghouse. https://www.aihw.gov.au/getmedia/7d54eac8-4c95-4de1-91bb-0d6b1cf348e2/ctgc-ip05.pdf?v=20230605181119&inline=true

Martin, K. (2008). Please knock before you enter: Aboriginal regulation of outsiders and the implications for researchers. *The Australian Journal of Indigenous Education, 38*(1), 110–112. https://doi.org/10.1375/S132601110000065X

Macdonald, M., Garvey, D., Gringart, E., & Hayward, K. (2022). *Recognising Indigenous knowledges is not just culturally sound, it's good science*. https://theconversation.com/recognising-indigenous-knowledges-is-not-just-culturally-sound-its-good-science-184444

Morgan, B. (2018). Beyond the guest paradigm: Eurocentric education and Aboriginal peoples in NSW. In E. A. McKinley & L. T. Smith (Eds.), *Handbook of Indigenous education*. Springer Singapore.

Reconciliation Australia. (2022). *2022 Australian reconciliation barometer*. https://www.reconciliation.org.au/wp-content/uploads/2022/11/2022-Australian-Reconciliation-Barometer-FULL-Report.pdf

Ristevski, E., Thompson, S., Kingaby, S., Nightingale, C., & Iddawela, M. (2020). Understanding Aboriginal peoples' cultural and family connections can help inform the development of culturally appropriate cancer survivorship models of care. *JCO Global Oncology, 6*, 124-132. https://doi. org/10.1200/JGO.19. 00109

Shay, M. (2023). *The big mob, STEM it up project*. The University of Queensland. https://education.uq.edu.au/big-mob-stem-it-project

Shay, M., & Oliver, R. (2021). Introduction. In M. Shay & R. Oliver (Eds.), *Indigenous education in Australia learning and teaching for deadly futures.* Routledge.

Tynan, L. (2021). What is relationality? Indigenous knowledges, practices and responsibilities with kin. *Cultural Geographies, 28*(4), 597-610. https://doi.org/10.1177/14744740211029287

Universities Australia. (2020). *Indigenous strategy 2017-2020.* https://universitiesaustralia.edu.au/wp-content/uploads/2019/06/Indigenous-Strategy-2019.pdf

Universities Australia. (2023, July). *Indigenous strategy annual report*. https://universitiesaustralia.edu.au/wp-content/uploads/2023/06/UA-2023-Indigenous-Strategy-Report.pdf

Walker, L., & Banks, C. (2021). *Indigenous STEM education project final evaluation report: September 2014 – June 2021*. CSIRO.

Study 4: International case studies

The STEM international case studies provide a better understanding into the complexities and nuances of practices within the global space. The different case studies examine how countries delineate their policies, manage practices, and address challenges within the field to contribute to the advancement of knowledge in STEM fields. These case studies thus provide an opportunity for Australia to apply knowledge from across the different case study contexts (New Zealand, Canada, and the United States of America) and facilitate cross-cultural understanding of those issues.

For the international case studies, there were certain criteria that were considered critical when selecting countries as comparative examples. The set criteria for selection and inclusion were as follows:

- The country must be from a colonised context with a distinct Indigenous population.
- The country has an established program or policy intervention with increased participation in a STEM field.
- There are peer-reviewed evaluations or publications on the success of the intervention.
- The chosen program demonstrates sustainability within the intervention design.

General key findings

The international case studies were drawn from three Western Indigenous contexts: New Zealand, Canada, and the United States of America. These countries generally have a wide percentage of Indigenous communities and a range of specific policies and programs that were introduced as part of their Indigenous STEM practices. In this report, there is a detailed outline of the national and Indigenous context (colonial history, similarities/differences to Australia) and STEM context for each case study.

Southeast Asian (SEA) countries were not selected for comparison due to the differing geo-political positioning of the society, the provision of schooling, the nature of schools, and the specific policies governing the schools especially pertaining to Indigenous context. There will be, however, a small segment that discusses generally how SEA countries support STEM initiatives within their contexts. This discussion will derive from data from the Australian Council of Learned Academies (ACOLA) evidence-based interdisciplinary research reports (Buntting et al., 2014).

The search for international case studies focused on policy reports, research papers, specific studies, and cross-comparative analysis across varying regions. There was a critical examination of the different stakeholders involved in education policy discourses; school, community, or government STEM initiatives; and the historical, cultural, and political contexts of different countries.

The search indicated that there was a comprehensive Indigenous STEM policy framework across the three countries selected, as well as integration of STEM activity across various domains, including schools, universities, industries, research and development, and communities. Centres, institutes, and agencies are critical establishments within STEM infrastructure, and these establishments are present across all three countries. The countries also have support systems stemming from policies that are disseminated from the ministerial level, which comprises government ministers and key association stakeholders and will be discussed in further detail in each case study sections.

STEM-focused policies support the creation and practice of STEM interventions (Ball, 1993, 2005). Across the three case study countries, national policy frameworks directly impact and support intervention practices. Overall, the case study countries feature strong national policy frameworks that focus on reconciliation efforts and recognise Indigenous rights. These policies are related to government funding and scholarships; inclusion and revitalisation of Indigenous languages in STEM fields; prioritising Indigenous innovations; and widening STEM opportunities. Specific targets that assist in advancing Indigenous STEM participation are discussed in detail within the case studies, as well as the strengths, commonalities, and distinct differences that have increased Indigenous participation in STEM.

STEM performance: Thriving contexts

Research has shown that there is a close correlation between countries that have thriving established economies and countries with strong STEM foundations, research, and performance (Timms et al., 2018). According to the Organisation for Economic Co-operation and Development's (OECD) Programme for International Student Assessment (PISA) on students' performance in STEM, the top three proficiency levels are in countries such as Singapore, China (Shanghai), Korea, Taiwan, Finland, and Switzerland (Marginson et al., 2013). The commonality across these countries is their commitment and established funding towards research and development. They also have thriving economic performance and heavily invest in their education system and teachers' professional development in STEM. For example, teachers in China are remunerated through salary increase when they continue professional development in STEM. For Singapore, there are centrally-funded programs including curricula revision and teaching standards with a focus on critical engagement in math and science through inquiry and problem-based learning, with emphasis on critical thinking and creativity. Within the South Korean context, there is a focus and shift to STEAM through an incorporation of arts into STEM. Such student-centred approaches are adopted without compromising the STEM content (Marginson et al., 2013).

STEM Indigenous issues and approaches

Despite the advances made in some STEM areas, important issues connected with Indigenous participation in STEM subjects and in the STEM workforce still need to be addressed (Garibay, 2015). This is clearly reflected in the New Zealand, Canada, and United States case studies. In these contexts, there is a general underrepresentation of students' participation in STEM. For example, in Canada, while there has been an increase of Saskatchewan Indigenous peoples in optional school science subjects between 2011 and 2022, participation rates for Indigenous students remain low overall (Aikenhead, 2013, p.14). In the United States, for American Indians (AI) and Alaska Natives (AN), there is underrepresentation and disadvantage in their STEM system due to prescribed approaches to school science and mathematics that are incompatible to their needs. Within the New Zealand system, the Māori and the Pasifika students underperform in the areas of mathematics and science (McKinley et al., 2014).

However, all three case study countries have national STEM policies that are targeted at meeting the economic demands for STEM skills and competitively positioning themselves within the current globalised economy (Freeman et al., 2019). These policies have been introduced to mitigate the declining performance of international mathematics and science assessments (e.g., TIMMS and PIRLS), and as a response to the 'STEM crisis' which has created urgent need for innovation in STEM fields (Freeman et al., 2019). **Table 17** shows some key initiatives introduced within the areas of STEM since 2015 in the different countries.

Table 17
Key STEM Initiatives Since 2015

Countries	Initiatives	Subject focus
New Zealand	National Statement on Science Investment 2015	Country's science system
United States	National STEM workforce strategy	STEM workforce
Canada	Saskatchewan K-12 curriculum	Science curriculum

Case study 1: New Zealand

Demographic context

The New Zealand context shows an ethnically diverse population over the past two decades, from increased migration ranging from countries such as Britain, South Africa, Pacific Islands, India, and China. Per 2018 census data, the six main ethnic groups in New Zealand are: European, Māori (the Indigenous population); Pacific Island peoples or Pasifika; Asian; Middle Eastern, Latin American, and African; and Other (Stats NZ Tatauranga Aotearoa, 2020). A critical point to state is that Aotearoa New Zealand ethnic identification is strong, which is mostly determined by the way the New Zealand government identifies its population (Kukutai & Webber, 2017). There is also the absence of segregated regions or reserves for Indigenous groups or 'quanta of blood' categorisation of peoples like in other countries, such as Australia, Canada, and the United States.

Political context impacting education

The Treaty of Watangi (ToW) is the founding document signed in 1840 between the British Crown and over 500 Māori rangatira (chiefs) where the British colonists were given the rights to settlement. Unlike Australia's status of terra nullius, the treaty guarantees "exclusive and undisturbed rights to Māori in terms of preservation of taonga (treasures), for example, land, fisheries, forest, language" (Royal Commission on Social Policy, 1987, p. 4). It also gave Māori the rights and privileges of British subjects.

Schools, however, became monocultural in language and curricula due to the: Native Schools Act 1867; national education system for Māori (1867); and national primary school curriculum (1877). This was a direct result of assimilation policies, causing loss of speaking and being well versed with the te reo Māori (Māori language). The loss of language was a deep concern and resulted in the setting up of the Te Taura Whirl i te Reo Māori (The Māori Language Commission) to ensure the use of the language in the school curricula and for other means. In 1987, New Zealand became an official bilingual nation with both Māori and English as official languages. Many Māori words have been incorporated into New Zealand English and, while there is an official dictionary on this (Keegan, 2017), few non-Māori speak the languages fluently. The loss of language before revitalisation has resulted in all Māori speaking English, but only 23% speaking te reo Māori (Kukutai, 2011).

Schooling and STEM education

STEM is described in the Ministry of Education's New Zealand Curriculum "within three discrete learning areas: science, technology and mathematics. Schools have responsibility for developing and implementing their own school-based curricula from these national documents” (Buntting et al., 2014, p. 5). Under the Kura kaupapa Māori (KKM) system (where students are immersed in Māori language and culture), there were complexities in setting up such an initiative, especially in STEM. One of the factors is the lack of Māori speaking STEM-qualified teachers.

At present, studies have shown that New Zealand has “one of the largest mathematical achievement gaps related to ethnicity across developed countries, with Pasifika students in New Zealand at a much greater risk of underachievement” (Hill et al., 2019, p.104).

In the New Zealand, there is similar rhetoric to that in other case study countries on the importance of STEM within a growing economy, but the enactment of such policies is complex because there is no linear and direct impact of such policies. An important thing to note is that the longstanding and large-scale reforms/initiatives in New Zealand within STEM areas have mostly been government funded. The initiatives have also been in specific subjects within STEM. Most initiatives are under evaluated and those that are evaluated still have gaps in the desired target areas. This is shown in **Table 18**.

Table 18
STEM Initiatives in New Zealand

Name of program	Year of program	Government policies and programs	Student / teacher/ curriculum focused	Impact and outcome
Growth and Innovation-Technology funding	Introduced in 2004. Long-term funding (2004-2013).	Funding for technology teachers’ professional development.	Professional development of technology teachers.	Under evaluated.
Science and Biotechnology Learning Hubs - Web based resources	Launched in 2005 and 2007. Funded by the Ministry of Business, Innovation and Employment.	Development of Science and Biotechnology Learning Hubs - Web based resources.	Student, teacher, and curriculum focused.	Under evaluated.
Te Kotahitanga - Professional development program	Conceptualised in 2001. Research-based professional development program in 2004.	Aimed at providing teachers with knowledge and skills for culturally responsive instruction (Bishop et al., 2007). Teachers build reciprocal relationship with their students through Māori concepts such as ako (co-construction of knowledge), manakitanga (demonstrating care),	Professional development of teachers. Student and teacher focused with parent engagement.	Evaluated, but the impact of culturally responsive pedagogies on STEM learning remains unknown. Conducted independent evaluation by an international research team (Savage et al., 2011). Higher levels of implementation of an ‘effective teacher profile’ -

Name of program	Year of program	Government policies and programs	Student / teacher/ curriculum focused	Impact and outcome
		and whānau (family).		positive learning experiences when teachers used culturally responsive practices.
Numeracy Development Project	Since 2001.	To improve and enhance numeracy skills in learners - includes mathematical and quantitative abilities.	Student and curriculum focused.	Young-Loveridge et al. (2012); Thomas and Tagg (2004); Trinick and Stevenson (2005) paper examines the effectiveness of the program and do show success to a certain extent. The more recent studies were critical of the success of the NDP project. No concrete data to ascertain the effectiveness. However, the reports did highlight the value of intense, prolonged professional development opportunities for teachers and schools.
Mathematics and Science Taskforce	Ministry of Education since 1997.	Publication 'Connected', a resource that aims at increasing students' interest in science, technology, and mathematics and alert readers to cutting-edge scientific research. Building Science Concepts (BSC) series.	Student, teacher, and curriculum focused.	Ongoing use of resource - Comprehensive teacher support materials for each book.

Below are some key examples of programs and policy intervention that were initiated in STEM, with a brief analysis of the success based on research on the stated intervention.

Program and policy interventions

As shown in **Table 18**, most of the programs started in the early 2000s and were targeted at one of the following areas: student, teacher, or curriculum development. Most of the projects have an overlap on the targets in the different areas, as seen from **Table 18**. While there has been long-term funding for some of the projects to allow for more strategic ways to engage within STEM, most of the programs remain under evaluated and do not have any concrete data to ascertain the effectiveness and sustainability of such programs.

Te Kotahitanga professional development program

One of the more sustainable initiatives is the professional development opportunities that have been made available since the earlier 2000's. For example, the Te Kotahitanga is a professional development program which targets at the provision of culturally responsive instruction for teachers (Bishop et al., 2007). The program originated in 2001 and is led by Māori researchers at the University of Waikato. There were several stages to the implementation process, with a formal model being rolled out to 12 pilot schools in 2004 and another 20 schools in 2007. One hundred secondary schools across New Zealand have participated in the program since 2010 (Alton-Lee, 2015).

A key goal of the program is developing caring and collaborative relationships with Māori students. Results from the program indicated higher levels of implementation and positive learning experiences when teachers adopt culturally responsive pedagogies (Alton-Lee, 2015). It has also shifted teacher attitudes and practices and is used as a model for culturally sustaining pedagogy in education (Siope, 2011).

Numeracy Development Project

Another example is the Numeracy Development Project, a long-sustained program that was developed in response to the Third International Mathematics and Science Study (TIMSS) to address the low mathematics achievement of students. This program received a lot of support and in its initial stages trained facilitators in 31 schools and is currently operating nationwide across 800 schools (Poskitt et al., 2009; Young-Loveridge, 2005; Young-Loveridge et al., 2012).

The program which started in primary schools has expanded to middle and secondary schools. There are multiple resources that are provided in support, such as lesson plans, assessment support materials, and activities that are aligned to national curriculum standards.

This program has received both positive and negative evaluations on its impact. Young-Loveridge's (2005) paper *Patterns of Performance and Progress on the Numeracy Development Project: Looking Back* examines the effectiveness of the program and shows improvement to a certain extent, but she warns against the homogeneity of the data. There were other studies from Thomas and Tagg (2004); Trinick and Stevenson (2005); and Anthony and Walshaw (2009) that also highlight success, but recent scholars have pushed back on the impact of educational success for students (Knight, 2005; Whyte & Anthony, 2012).

Overall, there was no concrete data to ascertain the effectiveness and sustainable impact of the program. There were independent evaluations as discussed above, but results were not conclusive in terms of students' improvement. The more recent studies were critical of the success of the Numeracy Development Project and its impact and effectiveness. Such concerns or limitations are valid and can help shape educational policy and practice. The reports do highlight the value of targeted, prolonged professional development opportunities for teachers and schools. The sustained mentoring and network support provided by the program allowed for positive changes in practice. We can see here the importance of professional development opportunities, like the one from the Te Kotahitanga program.

Mathematics and Science Taskforce

The Mathematics and Science Taskforce was conceptualised and established by the Ministry of Education in 1997. The main aim of the program was to target the improvement of mathematics and science in New Zealand schools. It was revisited in 2016, where the government took a more central role in reconstituting the taskforce under the leadership of Sir Peter Gluckman and Bev Cassidy-Mackenzie. The personnel involved proposed five key recommendations in 2018 and this contributed to a major STEM education investment involving 100 million NZD in targeted funding (Mathematics & Science Taskforce, 2018; Walters, 2019). These recommendations included: revised targets pertaining to student engagement; curricula changes; enhanced teacher training with new set of measurement tools for learning progressions; and a more targeted focus on implementation of recommendations (Johnston, 2021).

Case study 2: Canada

Demographic context

The Indigenous population in Canada is comprised of three distinct but ethnically diverse groups – First Nations, Métis, and Inuit – who are recognised in Canada's *Constitution Act, 1982*. As of the 2021 Census, Indigenous peoples made up 5% of the total population in Canada, which is larger than the Indigenous population in Australia (3.2% in that reporting period) (Statistics Canada, 2022). Canada is divided into ten provinces and three territories, with each locality having a unique Indigenous profile. For example, most Inuit live across Canada's three territories, which have a proportionately large Indigenous population due to the territories' overall smaller total population size (Aikenhead, 2013). Depending on locality, an estimated one-third to one-half of First Nations peoples live on reserves across Canada: a result of historic government policies and interventions with First Nations peoples. The Métis and Inuit peoples do not live on reserves (Aikenhead, 2013).

Political context impacting education

Similar to Australia, the history of colonisation in Canada has had significant and detrimental impacts on the Indigenous population, particularly with respect to education. Between 1870 and 1996, the Canadian government, in partnership with Christian churches, operated Indian Residential Schools, which were boarding schools designed to isolate Indigenous children from their families and assimilate and re-educate them under a Euro-Canadian education model (Wallace-Casey, 2022). The residential schooling system was supported by previous government policy, namely the *Indian Act* which was passed in 1876 and later amended in 1984 to impose compulsory schooling for First Nations children (Garusova, 2022).

Under the residential schooling system, Indigenous children suffered horrific abuse, profound cultural loss, and ongoing intergenerational consequences. In 2008, the Canadian government launched a Truth and Reconciliation Commission to examine the history and impact of the residential schooling system (Wallace-Casey, 2022). Through this Commission and its subsequent 94 Calls to Action issued in 2015, the Canadian government committed to reconciliatory actions and educational reforms for Indigenous peoples to remedy the impact of residential schools. This included recommendations for improving educational outcomes and success rates for Indigenous learners (Call 10), as well as developing culturally inclusive curricula and resources, and culturally capable educators (Calls 10, 62, and 63) (Truth and Reconciliation Commission of Canada, 2015).

Disparities exist in educational attainment and outcomes for Indigenous and non-Indigenous peoples in Canada. A review of statistical data from the government of Canada by Garusova

(2022) indicated that on and off reserve Indigenous populations had lower levels of high school completion compared with non-Indigenous Canadians, as well as lower levels of university degree completion. In 2020, 8% of Canadians aged 25-64 years did not finish high school and did not receive further education; for Indigenous peoples off reserve, this figure was more than two-times higher at 17%. In the same year, 34% of Canadians aged 25-64 had completed university degrees, while Indigenous peoples with completed university degrees in this age group was 14% (Garusova, 2022). Lack of high school completion directly impacts economic self-determination and the ability of the Indigenous population in Canada to pursue higher education and careers in STEM fields.

Schooling and STEM education

Under the *Constitution Act 1867*, Canada's provinces and territories have responsibility and jurisdiction for education. The exception to this is schooling on First Nations reserves, which is the federal government's responsibility (Anderson et al., 2021). As a result, "there is no nationwide education system, federal department of education, [or] national curriculum standard" (Anderson et al., 2021, p.2).

The Council of Ministers of Education, Canada (CMEC) is an intergovernmental body that facilitates the development of education guidelines at a national level and, in 1997, produced the *Common Framework of Science learning Outcomes K-12: Pan-Canadian Protocol for Collaboration on School Curriculum* (Cooper, 2020a). This framework has become "the dominant conceptual framework that underpins school science curriculum across the country", through its recommendation of embedding Indigenous perspectives under Social and Environmental Contexts of Science and Technology (Cooper, 2020a, p. 12). Despite the framework's adoption, the de-centralised nature of Canada's education system and variations in the composition of Indigenous populations across provinces and territories (Cooper, 2020a) means education governance and STEM curriculum, policy and initiatives vary considerably across the country.

Program and policy intervention

Interventions and programs to increase Indigenous participation in STEM in Canada can be broadly consolidated into three main areas: Kindergarten to Year 12 (K-12) schooling, tertiary bridging and support, and community outreach. Most interventions and programs are targeted towards science than other STEM fields, and there is an overall lack of evaluation and quantitative measurement of long-term impact in increasing Indigenous representation in STEM (Cooper, 2020a, 2020b). Despite this, Canada does have examples of interventions with longevity, which are highlighted in **Table 19**.

Table 19
STEM Initiatives in Canada

Name of Program	Year of program	Government policies and programs	Student / teacher/ curriculum focused	Impact and outcome
Saskatchewan K-12 Curriculum	Commenced 2005 (ongoing).	Common Framework of Science learning Outcomes K-12: Pan-Canadian Protocol for Collaboration on School Curriculum (1997). Inspiring Success: Building Towards Student Achievement, First Nations and Métis Education Policy Framework (2009). Inspiring Success: First Nations and Métis Pre K-12 Education Policy Framework (2018 - Current).	Science curriculum renewal embracing Indigenous and non-Indigenous knowledges. Pearson Science: Saskatchewan Edition textbooks with Indigenous knowledges for science classrooms.	Under-evaluated. Statistics refer to an increase in optional science course uptake by Indigenous students, however correlation appears speculative.
University of Manitoba's Education Access Program	Commenced 1985 (ongoing).	Unclear.	Focus on holistic student support to facilitate admission, retention and graduation from engineering degrees.	Consistent Indigenous graduation rates from engineering disciplines. Student support across academic, social, personal and financial areas.
University of Saskatchewan Science Ambassador Program	Commenced 2007 (ongoing).	Unclear.	Two-way learning focus with ambassadors, teachers, and students. Ambassadors facilitate activities for students and teachers, and programs are flexible and community specific.	Qualitative teacher and student feedback indicating better attendance in science, enrolling in higher level science courses, and interest in pursuing STEM careers.

K-12 schooling case study: Saskatchewan

As reflected in **Table 19**, in 2005, the Ministry of Education in the Province of Saskatchewan began a renewal of its core science curriculum to embrace First Nations, Métis and Inuit perspectives, thereby encouraging greater participation in science by Indigenous students (Aikenhead & Elliott, 2010, p. 329). This intervention was different from other provincial and territorial efforts in two ways. Firstly, Indigenous knowledges were recognised alongside Western scientific knowledges as a legitimate epistemology to understand the physical world and positioned as core to "each of the four units of study at each grade" (Aikenhead & Elliott, 2010, pp. 329-330). Secondly, to support the curriculum renewal, a series of customised science textbooks incorporating Indigenous knowledges and content were developed in partnership with Elders and Knowledge Keepers and published through national education publisher Pearson Education Canada (Aikenhead & Elliott, 2010, pp. 332-333). Released between 2011 and 2014, the Pearson Science: Saskatchewan Edition series covers Grades 1-9 and "represents the most comprehensive set of K-12 science materials in Canada that integrate Indigenous ways of knowing nature alongside Western approaches" in classroom science (Cooper, 2020a, p. 9).

The Saskatchewan curriculum renewal was based on the Pan-Canadian science framework and encouraged relationships between teachers and Indigenous community to ensure Indigenous place-based knowledges were taught within the appropriate region and time and in a culturally appropriate manner (Aikenhead & Elliott, 2010, pp. 332). Indigenous community stakeholders were heavily involved in the renewal of the curriculum and development of the science textbooks, and materials were piloted in schools with high Indigenous populations to assess suitability and refine before wider release (Aikenhead & Elliott, 2010, pp. 330-331). Thus, in Saskatchewan, education became a shared responsibility between government, schools, and the wider Indigenous community.

Authors reviewing the success of the curriculum renewal often cite the statistic of an 80% increase in Indigenous student enrolments in optional Grade 11 and 12 science courses between 2011 and 2022, and that this increase correlates to the success of curriculum initiatives because it cannot otherwise be explained by the increase in Canada's Indigenous population over the same period (Aikenhead, 2013, p. 14). However, this alone is not indicative of success and there does not appear to be targeted evaluations measuring student outcomes, including progression to related STEM careers or degrees after school. Nevertheless, as the program has spanned almost twenty years, it demonstrates sustainability and has uniquely produced textbooks alongside curriculum renewal that present Indigenous knowledges as equally important to Western knowledges.

Tertiary bridging and support case study: Engineering Access Program

Disparities in STEM K-12 education and lack of academic support and mentorship when transitioning to university can create barriers for Indigenous participation in post-secondary STEM programs. In 1985, the University of Manitoba launched the Engineering Access Program (ENGAP), which was a joint initiative between federal and provincial governments that arose from a mandate to increase admission and retention of Indigenous students in engineering programs (Herrmann, 2014, p. 1). To assist with admission, students who do not meet subject prerequisites can follow an adjusted program plan where they complete prerequisite courses in science, mathematics, and computing alongside their first-year courses. There is no cost for ENGAP students to complete prerequisite courses and these courses are ENGAP students have access to free tutoring, counselling, and bursary support, as well as assistance finding engineering-related employment during summer breaks and upon graduation which assist in attaining the intended outcome of the project (Herrmann, 2014, pp. 2-3).

The University of Manitoba has deemed this program “the most successful program of its type in Canada”, citing 95 graduates between 1985 and 2014 and averaging 4-7 graduates per year in recent years (Herrmann, 2014, p. 3). This is not a significant figure, but it does point to the longevity of the program. Moreover, unlike many universities’ bridging programs that just focus on admission, the ENGAP program holistically supports students academically, personally, and financially across the duration of their students from admission to graduation. As of 2023, the program is still running, thereby demonstrating sustainability. However, as with other programs, there is no quantitative evaluation of student impact.

Community outreach – Saskatchewan Science Ambassador Program

Many organisations across Canada offer STEM outreach programs for Indigenous youth across community and K-12 settings (Cooper, 2020b, p.8). A leading example of a community-based initiative is Actua’s Indigenous Youth in STEM program (InSTEM), which is designed to increase Indigenous engagement through culturally relevant STEM education experiences with close collaboration with Indigenous communities and leaders (Actua, 2022, p. 15). Notable features of current InSTEM programming include “land-based for-credit programming for Indigenous high school students” to increase high school graduation rates, as well as Actua Cultural Kits which challenge youth to “create a scaled model of an Indigenous cultural unit and learn about the Indigenous Knowledge that contributes to its innovative design and function” (Actua, 2022, p. 16). Actua has self-reported engagement with 35,000 First Nations, Métis, and Inuit youth and 200 Indigenous communities through their initiatives (Actua, 2022, p. 15).

The University of Saskatchewan’s Science Ambassador Program (SAP) is a unique Indigenous STEM outreach program that uniquely focuses on “two-way learning” relationship building to facilitate interest and engagement in STEM (Bonny, 2018). The program was piloted in 2007 from a mandate to increase minority representation in STEM, and through industry and government support has become a staple program of the University’s College of Arts and Science department since 2012 (Bonny, 2018, pp. 15-16). Ambassadors are selected from the university’s undergraduate or graduate STEM-related programs and placed in remote schools with “few or no specialist STEM instructors” and with a high Indigenous student enrolment (Bonny, 2018, p. 16). Two-way learning is enacted as ambassadors learn about Indigenous cultures from community placements, while preparing STEM activities for teachers to use to engage Indigenous students (Aikenhead, 2013, p.36). Between 2007 and 2012, the SAP program engaged with 4,570 students and 18 communities through three Prairie Provinces. Qualitative feedback from teachers and students over the life of the program have demonstrated a positive correlation with SAP placements and Indigenous student attendance in the science classroom, enrolling in higher level science classes, and interest in pursuing STEM careers (Aikenhead, 2013, pp. 36-37).

Case Study 3: United States of America (Alaksa)

Demographic context

The literature on the United States stood out due to the diversity of its demographics. This report focuses on Alaskan Indian and some discussion around American Indian involvement in the United States STEM system. The literature shows that the participation and graduation rates are significantly worse for these groups than other minority groups in the United States. Only 17 per cent of Alaskan Indian and American Indian have bachelor’s degrees and only three per cent were in STEM careers in 2009 (Marginson et al., 2013). This report will focus on varied issues within the cultural/ethical/spiritual issues that has affected Alaskan Indian and American Indian people’s success in STEM. The underrepresentation of Alaskan Indian and American Indian students in STEM stems from the deficit mindset that usually permeates discussion of issues pertaining to Alaskan Indian and American Indian access to higher education (Yosso & Solórzano, 2006).

Schooling and STEM education

Within education, the United States government's commitment to STEM can be seen in its federal legislation. The America COMPETES Act was introduced in 2007 by President Bush and reauthorised in 2010 by President Obama. The primary purpose of the Act has been promoting and investing in STEM education, research, and innovation to enhance global competitiveness (Council of Economic Advisers, 2010). There are huge gaps that exist in support of Alaskan Indian and American Indian access to STEM, despite a focus on the importance of K-12 STEM education. This includes gaps in advancing research and innovation; providing resources and clear mandates to federal science agencies such as National Science Foundation (NSF) and National Institute of Standards and Technology (NIST); and shaping federal science policy and investment.

The Bayer Corporation (2012), in its 15 years of study into issues relating to STEM, details the continued discrimination and biasness that exist in the education system, workplace and within society. This institutionalised prejudice, which targets at both minorities and women pursuing careers in STEM, is detrimental to the issues of Alaskan Indian and American Indian participation in these fields. Authors of the Bayer report (2021) state, "significant numbers of women and underrepresented minorities are missing the U.S. STEM workforce today because they were not identified, encouraged or nurtured to pursue STEM studies early on" (p. 7).

Underrepresentation of Alaskan Indian and American Indian individual in STEM is a significant issue that needs to be addressed. There are several factors that need to be considered which will be discussed in the later section but issues such as access to quality education, socioeconomic factors, cultural relevance, community support, and perpetuating stereotypes and bias hinders equitable opportunities within STEM. The need for collaborative work with Alaskan Indian and American Indian communities in implementing effective strategies for representation in STEM is critical (McKinley et al., 2012).

Program/policy intervention

As illustrated in **Table 20**, several local, state, and federal organisations assist in translating policies into practice. The United States approach is multilevel and targets different domains, specifically schools, colleges, and universities. For Alaska, there is a focus on both research development organisations and the broader community. Alaska's approach to STEM has been through a statewide STEM education plan. It focuses on curricula, teacher development, outreach programs with community, partnerships, and well-known initiatives such as Alaska Native Science and Engineering Program (ANSEP) as stated in **Table 20**.

Table 20
STEM Initiatives in the United States (Alaska)

Name of program	Year of program	Government policies and programs	Student / teacher/ curriculum focused	Impact and outcome
Native Science Connections Research Project (NSCRP)	Initiated in 2010 carried out in public, contract and BIA schools on the Navajo, Hopi, San Carlos Apache and Zuni reservations.	Culturally relevant science curriculum that integrates Native American students' traditional cultural knowledge with Western science (Gilbert, 2010).	Student and teacher focused.	Culturally based Science curriculum is able to improve students' achievement in Science and develop students' positive attitude in the subject.
Alaska Native Science & engineering Progamme (ANSEP)	Introduced in 1995 by Dr Herb Ilisaurri Schroeder, an Inupiaq and Dr Ray Barnhardt, a non-native Alaskan. Program introduced at the University of Alaska Anchorage.	Seeks to increase representation of Alaska Indigenous peoples in STEM fields. Support is rendered from middle through graduate school. Includes hands-on learning, internship and mentorship opportunities.	Student, teacher, and curriculum focused.	Success is attributed to holistic and comprehensive approach. Focuses on both academic and cultural identity and serves as a model for increasing diversity and representation in STEM education (Bernstein et al, 2015).
Math in a Cultural Context (MCC)	Initiated in 1990's and expanded in the next few decades.	Developed by the Alaska Native Knowledge Network (ANKN) at the University of Alaska Fairbanks to address the needs of Alaska Native students.	Student, teacher, and curriculum focused.	Statistically significant gains in learning as measured by pre- and post- tests conducted by Lipka and Adams (2004), and Nelson-Barber and Lipka (2008).
		Aimed at bridging the gap between Indigenous and Western knowledge in Math education. There is a focus on culturally responsive pedagogies that incorporates story-telling, hands-on learning, community involvement and cross-curricula integration.		In Alaska, students from *all* backgrounds who engage with Yup'ik culture-based curriculum showed statistically significant gains in achievement over peers using conventional curricula (Nelson-Barber & Lipka, 2008).

As can be seen in **Table 20**, key initiatives in STEM, the focus of United States efforts within the region of Alaska have been a longstanding approach towards culturally relevant approach to curricula, representation of Alaska's Indigenous peoples in STEM fields and bridging the gap between Indigenous and Western knowledge.

Native Science Connections Research Project (NSCRP)

The National Science Connections Research Project (NSCRP), which was initiated in 2010, aims to embed Indigenous knowledge into science education and focuses on developing culturally responsive pedagogies with various Indigenous communities. Learning is in connection to country, traditions and utilising Indigenous knowledge frameworks. Studies shows that such a culturally-grounded approach improves students' engagement and learning in science (Bang & Medin, 2014). At this stage, the development of curricula within the program has been small scale and the goal has been to implement the program more broadly (Bravo et al., 2018). One of the challenges of this program is balancing both Indigenous and Western knowledge (Bang & Medin, 2014). Moreover, there are issues on sustainability due to funding constraints and also seeking institutional/district support (Bravo et al., 2018).

Alaska Native Science and Engineering Program (ANSEP)

Introduced in 1995, the Alaska Native Science and Engineering Program (ANSEP) has evolved into one of the most longstanding programs aimed at different groups and levels within education: K-12 students; undergraduate students; graduate students; and educators. This program has attained several targeted goals for supporting Alaskan Indian and American Indian students in STEM. These include introduction of the Acceleration academy, a university success program, a mature scholar's program, internship opportunities (with major companies like BP, Boeing, NASA), and an alumni network (Bernstein et al., 2015). The focus of the above initiatives and program has been on the importance of culturally responsive pedagogy that incorporates Alaskan Indian and American Indian culture and traditions into the program, thus establishing a culturally affirming teaching and learning environment. Limitations of the program includes structural and institutional challenges such as teacher quality, curricula support, inconsistencies in school funding, accessibility, scalability of the program, and partner alignment (Kokeok, 2014; Bernstein et al., 2015). Rearden et al. (2016) also highlights similar issues around accessibility, limitations of expansion towards state-wide partnerships, and students' preparedness in mathematics and science.

Math in Cultural Context (MCC)

The Math in Cultural Context (MCC) program, like the NSCRP program, targets culturally responsive pedagogies and focuses on real life examples within Native communities. This program has been piloted and developed in several Alaskan Indian and American Indian communities. Research has shown higher test scores and engagement in comparison to conventional curricula. Limitations are similar to the other two programs where there are issues with scalability, teacher competency, standard alignment (Sternberg et al., 2007), and applicability (Jannok Nutti, 2013).

Lessons from international case studies

Similarities and strengths across the case studies

There are several notable strengths across the international case studies in New Zealand, Canada, and the United States in efforts towards STEM education. Generally, all the countries involved have shown a deep commitment to STEM development for Indigenous communities, with policies and programs in place. Strengths across the different contexts relate to strategic policies and programs introduced to advance Indigenous STEM participation; embedding Indigenous knowledges within curricula; specific funding support; and Indigenous leadership within education and professional domains. Overall, all three contexts have strong national policy frameworks that recognise Indigenous rights, with a focus on reconciliation efforts within the STEM fields.

Although there are distinctions in the histories, education systems, cultural groups, and languages, there are shared goals and approaches. Strengths of practice in all contexts include the following:

- Real life application of science and mathematics focusing on culturally responsive pedagogies that integrate Indigenous and Western knowledge systems.
- Place-based curricula that privileges Indigenous customs, traditional practices, connections to country and native languages.
- Indigenous community engagement and the alignment of approaches within each cultural context.
- Engagement with Elders, parents, and Indigenous communities and organisations to guide in program design and implementation.
- Established mentoring structures so that Indigenous learners have role models and mentors to generate interest and inspire them in STEM.
- Focus on both the theory and knowledge in Indigenous education and the culturally responsive ways of engagement.
- Priorities are given to teacher professional development and ensuring that teachers are skilled in using culturally responsive teaching strategies.
- Deep commitment to improve STEM achievement, to generate an interest in STEM in students, and increase self-efficacy for Indigenous learners.

Differences and limitations across the case studies

Despite the commonalities in practices across the varied regions, there are distinct differences and limitations that exist across the case studies in New Zealand, Canada, and the United States. Generally, the limitations flow from ensuring sustainable practices with the different programs and initiatives, the scaling impact of programs, the extent and contribution towards students' success in STEM, sustaining changes across time, and shifting education structures that impact on the development and success of the programs. However, gradual progress thus continues despite the limitations encountered.

Below are some issues that have surfaced:

- Navigating the tensions of standardised testing that hinders innovations in the STEM field.

- Scalability of programs beyond the pilot ones. There is evidence of sustained programs over decades without clear development and outcomes. There is thus the problem of consistent practices nationwide.
- Working towards balancing Indigenous and Western knowledge systems and pedagogies.
- Instability in funding opportunities that hinders sustainability for programs that support Indigenous STEM efforts.
- Co-construction of culturally responsive curricula with Indigenous community support.
- Equitable practices across the regions that will enhance accessibility to learning resources for Indigenous students in remote regions.
- Underrepresentation of Indigenous students in STEM fields is a much-needed area of concern. Statistics show that there is a consistent trend of lower percentage of Indigenous students pursuing STEM education as well as undertaking careers in STEM. This ongoing challenge is a result of inequitable access, historical exclusion, and a lack of cultural representation.

A major limitation within all the above issues is addressing the broader, systemic inequities that exist, which marginalise Indigenous students within mainstream educational systems and institutions. There is a need for fundamental systemic change that addresses the issues of self-determination for Indigenous communities. Thus, these changes need to go beyond just a pedagogical focus that have currently taken on a central role towards implementation. It is essential the underlying colonial structures that hinder Indigenous knowledge and education are addressed (Battiste, 2019; Tuck & Yang, 2012). This points to the need for greater Indigenous leadership that can exercise self-determination in education policy. There is a critical need to develop Indigenous leaders who fully understand cultural contexts to ensure that initiatives are well aligned to the needs, and most importantly values, of Indigenous communities across the varied domains (Kukutai & Walter, 2015). Leaders also act as key role models who can inspire young peoples and communities, mobilise sufficient resources, and establish important partnership with both institutions and community to support sustainable programs. Leaders in all forms – teacher leaders, community leaders, school leaders, and most importantly Elders – can drive transformational changes that can influence systemic policy shift. The voices and efforts of Indigenous leaders to direct the ways towards Indigenous governance and self-determination is an important step forward in attaining sustainable practices within educational institutions.

Conclusion

Advancing Indigenous STEM is an increasing focus for governments around the world, with concerns driven mainly by the links made between STEM education and research, and wealth creation. The international case study comparison identified strong commonalities across countries in their focus on Indigenous STEM participation and quality, but differences in policy and practice that could be broadly grouped according to economic regions. Concerns about Indigenous STEM participation differed in intensity, but the focus followed broadly similar patterns, including quality of education participation and outcomes in STEM; public perceptions of and engagement with STEM; recruitment into targeted STEM professions; supporting disadvantaged as well as elite groupings; and developing coherent policy that coordinated STEM effort. The particular focus and strategies depended on historical, cultural, and economic factors, with developing economies having distinctive foci for policy framing.

There is a need to extend the comparative analytic work of this study to pursue research that identifies the particular links between Indigenous STEM education foci, education more generally, and the nature and needs of emerging work futures. We also need to understand better the links between Indigenous STEM education, research, and the economic wealth of a country and wellbeing of its citizens.

References

Actua. (2022). *Actua's 2021/2022 annual report: Inclusive innovation in a post-pandemic world*. https://actua.ca/wp-content/uploads/2022/11/Actua_Annual-Report-2021-2022.pdf

Aikenhead, G. S. (2013). Science, technology, engineering and mathematics education and related employment for Indigenous students and citizens of Saskatchewan. *Australian Council of Learned Academies.* https://acola.org/wp-content/uploads/2018/12/Consultant-Report-Canada-Indigenous.pdf

Aikenhead, G. S., & Elliott, D. (2010). An emerging decolonizing science education in Canada. *Canadian Journal of Science, Mathematics and Technology Education, 10*(4), 321-338. https://doi.org/10.1080/14926156.2010.524967

Alton-Lee, A. (2015). *Ka Hikitia demonstration report: Effectiveness of Te Kotahitanga phase 5 2010-2012*. Ministry of Education, New Zealand Government. https://www.researchgate.net/publication/281627357_Ka_Hikitia_-_A_Demonstration_Report_Effectiveness_of_Te_Kotahitanga_Phase_5_2010_-_2012

Anderson, E. C., Easson, K., Beitari, S., Dakessian, M., Anand, S. P., Sachar, S., & Bou Nassar, J. (2021). Decolonization of STEM in the public education system in Québec, Canada. *Journal of Science Policy & Governance, 18*(4). https://doi.org/10.38126/JSPG180402

Bang, M., & Medin, D. (2014). Culture in the classroom: What is needed for bridging the gap between formal and informal science learning contexts? *Human Development, 57*(2-3), 135-140. https://doi.org/10.1159/000357185

Ball, S. J. (1993). What is policy? Texts, trajectories and toolboxes. *The Australian Journal of Education Studies*, *13*(2), 10-17. https://doi.org/10.1080/0159630930130203

Ball, S. J. (2005). *Education policy and social class: The selected works of Stephen J. Ball*. Routledge.

Battiste, M. (2019). *Decolonizing education: Nourishing the learning spirit*. UBC Pess.

Bayer Corporation. (2012, April). *STEM education, science literacy and in the innovation workforce in America: 2012 analysis and insights from the Bayer Facts of Science Education Surveys*. http://stem-works.com/system/pdfs/18/original/Final%20Bayer%20Compilation%20Report.pdf?1356048327

Bernstein, H., Martín, C., Eyster, L., Anderson, T., Owen, S., & Martin-Caughey, A. (2015). *Research report: Evaluation of the Alaska Native Science & Engineering Program (ANSEP).* Urban Institute. https://www.urban.org/sites/default/files/publication/39126/2000084-evaluation-of-the-alaska-native-science-and-engineering-program_1.pdf

Bishop, R., Berryman, M., Cavanagh, T., & Teddy, L. (2007). *Te Kotahitanga phase 3 whanaungatanga: Establishing a culturally responsive pedagogy of relations in mainstream secondary school classrooms.* Ministry of Education. https://thehub.swa.govt.nz/assets/documents/40792_Te_Kotahitanga_Phase3_0.pdf

Bonny, S. M. (2018). Effective STEM outreach for Indigenous community contexts – Getting it right, one community at a time! *International Journal of Innovation in Science and Mathematics Education, 26*(2), 14-34. https://www.proquest.com/scholarly-journals/effective-stem-outreach-indigenouscommunity/docview/2247805386/se-2?accountid=14723

Bravo, M., Mosley, M., & Solís, J. (2018). Early effects of the Native Science Connections Research Project on student learning. *Journal of Science Education for Students with Disabilities, 21*(1), 19-33. https://files.eric.ed.gov/fulltext/EJ1194734.pdf

Buntting, C., Jones, A., McKinley, L., & Gan, M. (2014). *STEM initiatives and issues in New Zealand*. Australian Council of Learned Academics. https://acola.org/wp-content/uploads/2018/12/Consultant-Report-New-Zealand.pdf

Cooper, J. (2020a, October). *Curriculum and reconciliation: Introducing Indigenous perspectives into K–12 science.* The Conference Board of Canada. https://edata.conferenceboard.ca/eLibrary/abstract.aspx?did=10772

Cooper, J. (2020b, June). *Incorporating Indigenous cultures and realities in STEM.* The Conference Board of Canada. https://edata.conferenceboard.ca/e-Library/abstract.aspx?did=10697

Council of Economic Advisers. (2010). *Economic report of the President.* United States Government. https://www.govinfo.gov/content/pkg/ERP-2010/pdf/ERP-2010.pdf

Freeman, B., Marginson, S., & Tytler, R. (2019). An international view of STEM education. In A. Sahin & M. Mohr-Schroeder (Eds.), *STEM education 2.0: Myths and truths - What has K-12 STEM education research taught us?* (pp.350–363). Brill.

Garibay, J. C. (2015). STEM students' social agency and views on working for social change: Are STEM disciplines developing socially and civically responsible students? *Journal of Research in Science Teaching*, *52*(5), 610-632. https://eric.ed.gov/?redir=http%3a%2f%2fdx.doi.org%2f10.1002%2ftea.21203

Garusova, L. (2022). Canada's contemporary policy on Aboriginal education. *SHS Web of Conferences, 134*, 1-7. https://doi.org/10.1051/shsconf/202213400013

Herrmann, R. (2014). The Engineering Access Program for Indigenous (First Nation/Metis/Inuit) students. *IEEE Canada International Humanitarian Technology Conference*. doi:10.1109/IHTC.2014.7147545

Hill, J., Hunter, J., & Hunter, R. (2019). What do Pasifika students in New Zealand value most for their mathematics learning. In P. Clarkson, W. T. Seah, & JS. Pang (Eds.), *Values and valuing in mathematics education: Scanning and scoping the territory* (pp.103-114).

Jannok Nutti, Y. (2013). Indigenous teachers' experiences of the implementation of culture-based mathematics activities in Sámi school. *Mathematics Education Research Journal, 25*(1), 57-72. https://doi.org/10.1007/s13394-012-004-x

Johnston, K. (2021, February 2). *Mathematics and science taskforce appointed*. Beehive.govt.nz. https://www.beehive.govt.nz/release/mathematics-and-science-taskforce-appointed

Knight, N. (2005). The contested notion of sustainability: Possibility or pipe dream for numeracy reforms in New Zealand. In P. Clarkson, A. Downton, D. Gronn, M. Horne, A. McDonough, R. Pierce, & A. Roche (Eds.), *Building connections: Research, theory and practice – MERGA28.* (pp.467-474). Mathematics Education Research Group of Australasia. https://educationgroup.co.nz/assets/resources/The-contested-notion-of-sustainability.pdf

Kokeok, O. A. (2014). Application of an Alaska Native Science and Engineering Program model to broader STEM programming. *Journal of Student Affairs Research and Practice, 51*(4), 364-375. https://doi.org/10.1515/jsarp-2014-0037

Keegan, P. J. (2017). Mäori dialect issues and Mäori language ideologies in the revitalisation era. *MAI Journal*, *6*(2), 129-142. doi:10.20507/MAIJournal.2017.6.2.3

Kukutai, T. (2011). Building ethnic boundaries in New Zealand: Representations of Maori identity in the census. In P. Axelsson & P. Sköld (Eds.), *Indigenous peoples and demography: The complex relation between identity and statistics* (pp.33-54). Berghahn Books. https://doi.org/10.1515/9780857450036-006

Kukutai, T., & Walter, M. (2015). Recognition and indigenizing official statistics: Reflections from Aotearoa New Zealand and Australia. *Statistical Journal of the IAOS*, *31*(2), 317-326. https://doi.org/10.3233/sji-150896

Kukutai, T., & Webber, M. (2017). Ka Pū Te Ruha, Ka Hao Te Rangatahi: Maori identities in the twenty-first century. In A. Bell, V. Elizabeth, T. McIntosh, & M. Wynyard (Eds.), *A land of milk and honey? Making sense of Aotearoa New Zealand* (pp.71–82). Auckland University Press.

Lipka, J., & Adams, E. (2004). *Culturally based math education as a way to improve Alaska Native students' math performance.* The Appalachian Collaborative Center for Learning, Assessment and Instruction in Mathematics Series. http://acclaim.coe.ohiou.edu/rc/rc_sub/pub/3_wp/list.asp

Johnston, K. (2021, February 2). *Mathematics and science taskforce appointed.* Beehive.govt.nz. https://www.beehive.govt.nz/release/mathematics-and-science-taskforce-appointe

Marginson, S., Tytler, R., Freeman, B., & Roberts, K. (2013). *STEM: Country comparisons: International comparisons of science, technology, engineering and mathematics (STEM) education. Final report.* Australian Council of Learned Academies. https://acola.org/wp-content/uploads/2018/12/saf02-stem-country-comparisons.pdf

Mathematics and Science Taskforce. (2018). *Recommendations for strengthening maths and science education.* Ministry of Education. https://mathsandscience.education.govt.nz/assets/Uploads/Mathematics-and-Science-Taskforce-Recommendations-for-strengthening-maths-and-science-education.pdf

McKinley, B., Brayboy, J., Fann, A. J., Castagno, A. E., & Solyom, J. A. (2012). *Postsecondary education for American Indian and Alaska Natives: Higher education for nation building and self-determination.* John Wiley & Sons.

McKinley, E., Gan, M., Buntting, C., & Jones, A. (2014). New Zealand: Towards inclusive STEM education for all students. In B. Freeman, S. Marginson, &R. Tytler (Eds.), *The age of STEM: Educational policy and practice across the world in science, technology, engineering and mathematics* (pp.201-214). Routledge. doi:10.4324/9781315767512

Nelson-Barber, S., & Lipka, J. (2008). Rethinking the case for culture-based curriculum: Conditions that support improved mathematics performance in diverse classrooms 1. In *Language, culture, and community in teacher education* (pp. 99-123). Routledge.

Poskitt, J., Anthony, G., & Taylor, M. (2009). *Improving outcomes for Māori and Pasifika students through the professional development of their teachers.* Ako Aotearoa National Centre for Tertiary Teaching Excellence.

Rearden, B., Ginsburg, H. P., Smith, J. J., Stump, L., Callahan, R. M., & Steward, R. (2016). An evaluation of the Alaska Native Science & Engineering Program (ANSEP). *Journal of STEM Education, 17*(3). https://www.jstem.org/index.php?journal=JSTEM&page=article&op=view&path%5B%5D=2187

Royal Commission on Social Policy. (1987). *A fair and just society*. Wellington, NZ.

Savage, C., Hindle, R., Meyer, L. H., Hynds, A., Penetito, W., & Sleeter, C. (2011). Culturally responsive pedagogies in the classroom: Indigenous student experiences across the curriculum. *Asia-Pacific Journal of Teacher Education, 39*, 183–198. doi:10.1080/1359866X.2011.588311

Siope, A. (2011). The schooling experiences of Pasifika students. *Set: Research Information for teachers, 3,* 10–16. NZCER Press. https://hdl.handle.net/10289/7447

Statistics Canada. (2022, 21 September). *Indigenous population continues to grow and is much younger than the non-Indigenous population, although the pace of growth has slowed*. https://www150.statcan.gc.ca/n1/daily-quotidien/220921/dq220921a-eng.htm?indid=329901&indgeo=0

Stats NZ Tatauranga Aotearoa. (2020, September 3). *Ethnic group summaries reveal New Zealand's multicultural make-up*. https://www.stats.govt.nz/news/ethnic-group-summaries-reveal-new-zealands-multicultural-make-up

Sternberg, B. J., Kaplan, K. A., & Borck, J. E. (2007). Enhancing adolescent literacy achievement through integration of technology in the classroom. *Reading Research Quarterly, 42*(3), 416-420. https://doi.org/10.1598/RRQ.42.3.6

Timms, M. J., Moyle, K., Weldon, P. R., & Mitchell, P. (2018, May). Challenges in STEM learning in Australian schools: Literature and policy review. *Policy Insights,* (7). Australian Council for Educational Research. https://research.acer.edu.au/cgi/viewcontent.cgi?article=1007&context=policyinsights

Truth and Reconciliation Commission of Canada. (2015). Truth and Reconciliation Commission of Canada: Calls to Action. *National Centre for Truth and Reconciliation, University of Manitoba.* https://ehprnh2mwo3.exactdn.com/wp-content/uploads/2021/01/Calls_to_Action_English2.pdf

Tuck, E., & Yang, K. W. (2012). Decolonization is not a metaphor. *Decolonization: Indigeneity, Education & Society, 1*(1), 1–40. https://www.researchgate.net/publication/277992187_Decolonization_Is_Not_a_Metaphor

Wallace-Casey, C. (2022). Teaching and learning the legacy of residential schools for remembering and reconciliation in Canada. *History Education Research Journal*, *9*(1), 1-18. https://doi.org/10.14324/HERJ.19.1.04.

Walters, L. (2019, May 12). *Government announces $113m plan to boost maths and science learning.* Stuff. https://www.stuff.co.nz/national/education/112641306/government-announces-113m-plan-to-boost-maths-and-science-learning

Whyte, J., & Anthony, G. (2012). Maths anxiety: The fear factor in the mathematics classroom. *New Zealand Journal of Teachers' Work*, *9*(1), 6-15. https://www.researchgate.net/publication/260710496_Maths_anxiety_The_fear_factor_in_the_mathematics_classroom

Yosso, T. J., & Solórzano, D. G. (2006). *Leaks in the Chicana and Chicano educational pipeline. Latino Policy & Issues Brief. Number 13.* UCLA Chicano Studies Research Center (NJ1). http://files.eric.ed.gov/fulltext/ED493404.pdf

Young-Loveridge, J. (2005). Fostering multiplicative thinking using array-based materials. *Australian Mathematics Teacher, 61*(3), 34-40. http://files.eric.ed.gov/fulltext/EJ743571.pdf

Young-Loveridge, J., Bicknell, B., & Prescott, S. (2012). *Developing mathematics-specific dispositional identities in middle-school students.* Mathematics Education Research Group of Australasia.

Key findings and recommendations

The *Big Mob: STEM it Up* research project has developed new evidence-based and Indigenous-informed understandings about increasing Aboriginal and Torres Strait Islander participation in STEM fields. Using multimethod approaches incorporating Indigenous methodologies such as yarning (Bessarab & Ng'andu, 2010) and community-based sampling (Woodley & Lockard, 2016), and by being underpinned by Rigney's (1999) Indigenist theory, this research has resulted in new and novel knowledge. This report outlined findings from each research study, including two systematic literature reviews, a community-based survey of 204 participants, qualitative interviews (transformed into podcasts), and international case studies. This report concludes by synthesising these findings that support evidence-based recommendations for future direction in increasing Indigenous participation in STEM fields.

The *Big Mob: STEM it Up* research project investigated the existing evidence base and developed new, empirical knowledge to advance evidence-informed recommendations to increase Indigenous participation in STEM. While there is no national reporting mechanism that monitors Indigenous participation in STEM, the Office of the Chief Scientist (2020) reported that "Aboriginal and Torres Strait Islander peoples are underrepresented in STEM, particularly at the university level, where 0.5% of the Aboriginal and Torres Strait Islander population had a STEM qualification, compared to 5% of the non-Indigenous population" (p.12). The data from *Australia's STEM Workforce* report suggests significant disparities in Indigenous participation in the STEM workforce exist (Office of the Chief Scientist, 2020).

Below are the key findings to emerge from The *Big Mob: STEM it Up* research, followed by recommendations for action.

The *Big Mob: STEM it Up* key findings

The *Big Mob: STEM it Up* research resulted in 22 key findings:

1. Most knowledge produced about Indigenous participation in STEM or Indigenous STEM knowledges is produced by non-indigenous researchers.
2. The recognition and valuing of Indigenous STEM knowledges was identified across the data as critical for advancing Indigenous participation in STEM and advancing Western STEM fields.
3. Science dominated the data in this research. When investigating Indigenous participation in STEM, it was evident that there has been a narrow emphasis on science, and that technology, engineering and mathematics are areas for development.
4. The existing identified literature on Indigenous participation in STEM is small and relatively recent (emerging in the past 20 years).
5. Just under one-quarter of Indigenous participants from the survey data reported that they did not know what STEM meant or was. This finding provides key evidence for future approaches to increasing Indigenous participation in STEM.
6. The evidence showed a significant lack of scholarly and independent evaluations of Indigenous STEM policy and program interventions.

7. Existing research focused heavily on Indigenous participation in STEM in education contexts. The data from Indigenous people in this study shows that the greatest influence, on their interest and study/careers in STEM, is from their family and community.
8. A body of the identified research focused on remote community settings, but there is a gap in regional and urban settings.
9. Most Indigenous people who contributed to this research reported an interest and positivity toward the possibilities of STEM individually, and for their communities.
10. The systematic literature review highlights mostly educational barriers to Indigenous participation in STEM. The survey data showed different barriers identified by diverse Indigenous people. These were ranked accordingly: 1) institutional barriers such as racism; 2) individual support and self-confidence; 3) affordability; 4) awareness of STEM; and 5) educational barriers.
11. Mentoring was important across all data. One new aspect of mentoring to emerge was the significance of family and community as a source of guidance, inspiration, and support.
12. Indigenous STEM initiatives were spoken about positively across the data. These appear to have a positive impact for some Indigenous people.
13. International studies from New Zealand, Canada, and the United States of America (Alaska) showed that applied approaches and hands-on learning appear to have positive impacts on increasing Indigenous participation in STEM.
14. International case studies demonstrated the importance of Indigenous input into program design.
15. The issue of educational barriers surfaced in all data. The barriers are connected to broader Indigenous education imperatives such as the overall goal to deliver positive educational outcomes for Indigenous people.
16. There is limited literature on Indigenous STEM recruitment, retention, and researcher development in higher education.
17. The evidence produced in this research shows a significant gap in industry-based research and Indigenous participation in STEM.
18. The evidence produced in this research shows that programs and research on Indigenous participation in STEM, undertaken collaboratively and using co-design approaches, support better outcomes.
19. There is a gap in research on the role of the Indigenous business sector and Indigenous participation in STEM.
20. As there is limited research overall on the topic of Indigenous participation in STEM, there was limited identified research investigating other forms of diversities within the Indigenous population and the impacts on their participation rates in STEM.
21. The evidence showed that there is a very limited body of research the includes the voices of Indigenous young people. The *Big Mob: STEM it Up* research did not have the capacity to include young people in this study, so this gap remains.
22. There is very limited research that explores Indigenous STEM engagement in the early years.

Recommendations for future policy and program intervention to increase Indigenous participation in STEM

The following presents 15 recommendations for future policy and program intervention to increase Indigenous participation in STEM.

Recommendation 1: Development of a national program to increase Indigenous STEM researchers.

The field of STEM requires Indigenous peoples to advance Indigenous knowledges. It is currently unknown how many Australian universities employ Indigenous STEM researchers or whether STEM higher degree research pathways are encouraged by universities. An investment in consolidating and understanding the current cohort and planning for supporting an increased Indigenous STEM workforce is urgently needed, as it is strongly connected to the overall goal of increasing Indigenous participation in STEM.

Recommendation 2: Advancing Indigenous STEM knowledges.

The criticality of recognising, valuing, and advancing surfaced across all data. Both Indigenous peoples and Western scientists advocate for advancing Indigenous STEM knowledges for the benefit of the field, as well as in the quest to increase Indigenous participation in STEM. Advancing Indigenous knowledges requires research investment and university-based infrastructure to develop a cohesive approach. Advancing Indigenous knowledges should also include a clearinghouse of trusted sources for educators (school and university-based) in embedding Indigenous STEM knowledges in curricula.

Recommendation 3: Urgent investment in Indigenous participation in technology, engineering, and mathematics.

The evidence demonstrates an emphasis on science in understanding Indigenous participation in STEM. Policy and program interventions should be developed to address Indigenous participation in technology, engineering, and mathematics.

Recommendation 4: Community-based campaign to increase awareness of STEM.

The evidence generated from the *Big Mob: STEM it Up* research demonstrates that some Indigenous people have language and cultural barriers in understanding what STEM is and what opportunities there are to be involved. An Indigenous-led campaign aimed at breaking down barriers is needed to demystify language and create a greater awareness among diverse Indigenous peoples.

Recommendation 5: Independent program and policy evaluation.

The evidence highlights a gap in rigorous, independent, scholarly evaluation of policy and program interventions on increasing Indigenous participation in STEM. This recommendation includes investigating opportunities for retrospective and future evaluation of policy and program interventions. These evaluations should include Indigenous researchers and funding to resource adequately.

Recommendation 6: Strengthen relationships between governments, the higher education sector, and NISTEMPN.

In 2020, an inaugural gathering of Indigenous STEM professionals formed the development of the National Indigenous STEM Professional Network (NISTEMPN). Much of the evidence outlined in the *Big Mob: STEM it Up* research highlights the importance of Indigenous input into program and policy design. NISTEMPN is an important network in growing Indigenous participation in STEM.

Recommendation 7: Creation of a research priority that investigates Indigenous STEM possibilities in urban and regional communities.

There is a strong existing evidence base on Indigenous participation in STEM and Indigenous STEM knowledges in remote communities in Australia. The focus on remote communities is at odds with Australian Bureau of Statistics (2022) data that shows only 9.1% of Indigenous peoples live in very remote Australia and 5.4% live in remote Australia. As most Indigenous Australians live in major cities (41.1%), inner regional areas (25.1%) and outer regional areas (18.5%), it is critical that further research explores both Indigenous participation in STEM and Indigenous STEM knowledges where most of the Indigenous population resides.

Recommendation 8: Establishment of an Office for Indigenous STEM.

Centralising efforts to increase Indigenous participation in STEM would have more impact if the resources and efforts were centralised into an ambassador model like that of the Office of the Australian Government’s Women in STEM Ambassador. The international case studies outlined a successful exemplar from Canada, the Saskatchewan Science Ambassador Program (SAP), a unique Indigenous outreach program working between community, industry, schools, and universities. The aim of this model should be to increase Indigenous participation in STEM, monitor data, champion Indigenous STEM knowledges, and inform policy development.

Recommendation 9: STEM mentoring programs.

Strong evidence supports the value of mentoring at all STEM career phases. Mentors include Indigenous role models, such as Elders and other knowledge holders from Indigenous communities. Developing a mentor program that is Indigenous led for Indigenous STEM professionals who are isolated and want to access mentoring may support recruitment and retention in STEM fields.

Recommendation 10: Explore non-traditional pathways to STEM careers.

The *Big Mob: STEM it Up* data highlights many examples of Indigenous people identifying STEM skills they used in their family through their cultural knowledge or community. The data also shows that, while most policy or program interventions focus on formal education experiences, Indigenous people are following diverse pathways to undertake professional roles and contribute to STEM fields. These non-traditional pathways could be explored through traineeships, certificate and diploma level qualifications, work experience, and Indigenous business sector employment.

Recommendation 11: Align Indigenous STEM goals with broader Indigenous education policy imperatives.

Educational experiences and broader educational issues such as racism, lack of inclusion of Indigenous knowledges, and socioeconomic factors were raised frequently across the data. Any policy or program approaches to increasing Indigenous participation in STEM should align with broader Indigenous education policy imperatives to strengthen and address broader Indigenous educational disparities.

Recommendation 12: Implementation of community-based STEM programs.

The data from Indigenous people in the *Big Mob: STEM it Up* research clearly demonstrates the significance of family and community as a strength for Indigenous peoples pursuing STEM education and careers. Therefore, community-based STEM programs to raise awareness of STEM opportunities and existing STEM potential in communities should be piloted.

Recommendation 13: Growing industry-based research.

There is a clear gap (particularly in technology, engineering, and mathematics) in industry-based research. Industry-based research is vital, as understanding the issue of Indigenous participation in STEM through understanding employer and industry-based contexts provides a deeper understanding of preparing Indigenous peoples for STEM careers.

Recommendation 14: Engaging Indigenous young people in understanding problems and solutions.

The absence of Indigenous young people's voices in the literature and in this research means there are limited young people's perspectives on Indigenous participation in STEM. Research and policy engagement activities are required to understand Indigenous young people's perspectives on Indigenous STEM and Indigenous participation in STEM.

Recommendation 15: STEM awareness from early childhood.

Evidence from the data suggests that embedding STEM perspectives into early childhood education provides children with the opportunities to experience STEM from an early age, potentially influencing study choices later in their educational experiences. STEM perspectives should include Indigenous STEM perspectives.

References

Australian Bureau of Statistics. (2022). *Census of population and housing counts of Aboriginal and Torres Strait Islander Australians*. https://www.abs.gov.au/statistics/people/aboriginal-and-torres-strait-islander-peoples/census-population-and-housing-counts-aboriginal-and-torres-strait-islander-australians/latest-release

Bessarab, D., & Ng'andu, B. (2010). Yarning about yarning as a legitimate method in Indigenous research. *International Journal of Critical Indigenous Studies*, *3(*1), 37–50. https://doi.org/10.5204/ijcis.v3i1.57

Office of the Chief Scientist. (2020*). Australia's STEM workforce: Science, technology, engineering and mathematics.* Australian Government. https://www.chiefscientist.gov.au/sites/default/files/2020-07/australias_stem_workforce_-_final.pdf

Rigney, L. I. (1999). Internationalization of an Indigenous anticolonial cultural critique of research methodologies: A guide to Indigenist research methodology and its principles. *Wicazo Sa review*, *14*(2), 109-121.

Woodley, X. M., & Lockard, M. (2016). Womanism and snowball sampling: Engaging marginalized populations in holistic research. *The Qualitative Report*, *21*(2), 321-329.

THE UNIVERSITY OF QUEENSLAND
AUSTRALIA
CREATE CHANGE

Contact details

Associate Professor Marnee Shay

School of Education, The University of Queensland
T +61 7 **3365 6484**
E m.shay@uq.edu.au
W uq.edu.au

CRICOS Provider 00025B • TEQSA PRV12080