Best Practice Principles for Community Science Engagement Programs

August 2025

Queensland Government

Prepared for:
Chief Scientist Coordination and Engagement, Science Development and Office of the Queensland Chief Scientist Branch, Department of the Environment, Tourism, Science and Innovation.

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Executive Summary

This report was commissioned to provide evidence-based guidance for the design, delivery, and evaluation of community science engagement programs across Queensland and beyond. It aims to support government, education, industry, and community stakeholders to ensure that engagement initiatives are impactful and aligned with Queensland's broader science, innovation, and workforce strategies as well as the Queensland Chief Scientist's emphasis on building community capacity in, and engagement with, science.

Context and Rationale

Queensland's vast geographic reach, diverse population, and economic variation present unique challenges and opportunities for community engagement. At the same time, global and national trends point to the urgent need for scientifically informed citizens who can navigate complex issues – including climate change and public health, to environmental sustainability, emerging technologies and mis- or dis-information. This report recognises that, to be successful, community engagement programs must reflect the diversity of local communities and build on the assets, knowledge, and leadership already present within them.

Best Practice Principles

Drawing on a comprehensive scoping review of peer-reviewed and grey literature, and informed by practitioner expertise in community science programs, this review presents a set of 13 best practice principles that provide a clear and practical framework for practitioners and decision-makers alike. These principles are grouped into two interconnected categories:

Design Principles, which guide how programs are structured and delivered

1. Establish Clear, Concise and Relevant Objectives and Goals
2. Employ Fit-for-Purpose Evaluation Approaches and Methodologies
3. Develop Program Capabilities and Capacity
4. Design for Sustainability and Scalability
5. Establish Strategic Alliances – Collaborations and Partnerships
6. Design for Inclusivity and Accessibility

Science Engagement Principles, which shape the nature and quality of the scientific engagement

1. Adopt Inquiry-Based Learning Approaches
2. Incorporate Hands-on Experiential Learning
3. Engage Relatable Scientists
4. Influence the Influencers
5. Utilise Informal Learning Places and Programs
6. Connect with Formal Education
7. Leverage Local Context and Local Resources

The distinction between the two sets of principles is deliberate. The *Design Principles* are non-discipline-specific and underpin the success of *any* community engagement program. They have a strong emphasis on planning, evaluation, collaboration, building capability and capacity, sustainability, and the removal of systemic barriers to access. These principles help practitioners shape the overall design structure and delivery parameters of the program.

By contrast, the *Science Engagement Principles* focus on the experiential and educational dimensions of community science engagement, including what participants experience, how they interact with scientific content, who they interact with in science, and what learning or self-identity development occurs as a result. These principles emphasise the importance of sparking curiosity and interest, modelling scientific thinking and practice, building science capital and identity, and making science relevant.

Each principle is underpinned by strong theoretical foundations and evidence-based practice. To support implementation, the report provides operational advice based on existing, validated frameworks, models and approaches.

Key Findings and Insights

The key overall insight derived from the review is the centrality of science capital in framing and evaluating program design, delivery and impact. Programs that enhance science capital – by affecting what individuals know, how they think, what they, do, and who they know in relation to science – are more likely to have sustained impact on attitudes, aspirations, and career pathways.

The findings also emphasise the importance of co-design, inclusive and place-based learning, cultural responsiveness, and the development of long-term collaborative partnerships with key people and organisations. Programs that adopt community asset-based approaches – focusing on local strengths rather than deficits – demonstrate increased community ownership and sustainability. The inclusion of relatable scientists and relevant local role models is shown to improve participant engagement, especially among underrepresented groups. Integration with both formal and informal education sectors, support for teachers, and links to curriculum further enhance the effectiveness and legitimacy of community-based programs.

Strategic Recommendations

Seven high-level recommendations support the implementation of the principles:

1. *Set clear goals, objectives and intended outcomes appropriate for the target audience with practical means of evaluating program effectiveness.*
2. *Develop strategic alliances to build program capacity, capabilities, and sustainability.*
3. *Embed inclusivity and accessibility in all aspects of program design, delivery and evaluation.*
4. *Incorporate inquiry-based and active experiential learning approaches, addressing both science understandings and scientific process skills.*
5. *Engage key influencers of youth choice including parents, teachers, friends as well as relatable scientists and culturally relevant role models.*
6. *Connect with educators and STEM engagement professionals in both formal and informal learning environments.*
7. *Ensure locally relevant contexts, resources and people are central to program design and delivery.*

Together, these recommendations and principles offer a flexible, evidence-based framework for designing and delivering high-quality, inclusive, and impactful community science engagement programs. They can be used to design new programs, evaluate existing initiatives, guide funding decisions, and promote cross-sector collaborations and partnerships.

When embedded thoughtfully, these best-practice approaches support co-designed, culturally responsive, and sustained engagement. Applied consistently, they can enhance science capital, strengthen community relationships with science, and ensure that programs remain adaptable, meaningful, and sustainable.

While every community and context are different, the principles outlined here are adaptable and provide a shared understanding and set of standards for excellence in community science engagement. Rather than serving as a one-size-fits-all checklist, they are intended to be adapted to the specific needs, contexts, and aspirations of diverse communities and programs across Queensland and beyond.

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1.0 Background and Rationale

"We live in a society exquisitely dependent on science and technology, in which hardly anyone knows anything about science and technology". **Carl Sagan**

The Queensland Government, through the Department of the Environment, Tourism, Science and Innovation and the Queensland Chief Scientist, recognises science and innovation as critical to Queensland's future prosperity, facilitating better outcomes for the environment, the economy and its people.

The Queensland Chief Scientist has identified five strategic focus areas for her role. One key focus is *Community Engagement,* which aims to bridge the gap between the scientific community and the public, enhancing scientific understanding, building trust, and developing a talent pipeline for the future. This focus further recognises that an engaged, scientifically literate citizenry is vital for building an informed and future-ready Queensland.

Four key goals will guide the development of future community science engagement programs delivered and/or supported by the Queensland government.

The first goal, to ***elevate public awareness and appreciation of science and innovation***, emphasises the importance of making science accessible and relatable to all Queenslanders, regardless of cultural background or geographical location. By raising awareness and highlighting the importance of science, this goal aims to promote a state-wide culture that values science and builds trust in the scientific community.

The second goal is to ***champion science literacy and critical thinking as essential civic skills***. This goal recognises that scientific literacy is key to an informed society. The aim is to enhance public understanding of science concepts and processes and equip individuals with skills to critically evaluate scientific information. This will allow Queenslanders to make informed decisions in their personal and professional lives, in a time characterised by rapid technological change and complex societal challenges.

The third goal focuses on ***expanding opportunities for scientists to meaningfully connect with the community***. Programs that promote active engagement between scientists and the public assist in breaking down barriers, demystifying science, reducing scepticism, and enhancing trust and credibility in science, scientists, and scientific institutions.

The fourth goal is to ***promote STEM careers to build a robust talent pipeline for the future workforce***. To address future workforce demands, community engagement programs will need to target a range of age-groups and demographics, showcasing multiple and diverse pathways to STEM careers. Key considerations include developing programs that:

- cultivate an interest in STEM from an early age
- promote post-compulsory (Year 10) school studies in science and mathematics
- influence the influencers of student choice – in both study and career pathways
- facilitate exposure to practicing scientists and relatable role models, and
- specifically engage underrepresented groups in the current STEM workforce.

This will maximise the full potential of the talent pool available, critical for ensuring that Queensland has the skilled professionals needed to drive innovation and compete in a rapidly evolving global economy.

To assist in achieving these goals, this document articulates a series of evidence-based, best-practice principles to support the development of impactful community science engagement programs. These principles were identified and developed through an extensive scoping review of peer-reviewed literature focussing on characteristics proven to enhance community engagement. Each principle is grounded in theoretical insights and evidence-based research, providing a robust rationale for its adoption. Additionally, practical implementation advice is provided, offering operational guidance for integrating these principles into program design and delivery.

1.1 The Queensland Context

Queensland shares similar challenges to other jurisdictions across Australia (and indeed the rest of the world) when it comes to community engagement in science. These challenges include:

Funding constraints – limited funding restricts the scope and scale of science engagement initiatives.

Human resource constraints – lack of expertise and skills in delivering quality science engagement programs restricts scope and scale.

Measuring impact – measuring the effectiveness of science engagement interventions (both long and short term) and understanding their impact on public attitudes, behaviours and choices is complex.

Scepticism and science denial – misinformation, dis-information, scepticism and science denial (often generated through political alignment) can hinder the effectiveness of community engagement programs.

Science can be difficult – effectively communicating complex scientific concepts, the methods employed by scientists, and the inherent uncertainties and associated risks in an accessible and understandable manner can be difficult. There is typically a gap between scientific language and public understanding, which is further complicated by the challenges of communicating the provisional nature of scientific knowledge, probability and risk ("*One in 100-year event*" … means a 1% chance of occurring in any year, not that it will occur exactly once every 100 years).

Science changes – science understandings change with time and context (*"Is caffeine good for you or bad for you?"* … it depends!!). This can be confusing and frustrating for the public. Moreover, rapid scientific and technological advancements often make it difficult to keep the public informed and engaged with current issues and developments.

1.1.1 Queensland specific challenges

Queensland is big and diverse – Queensland has highest proportion of people living in rural and remote regions of all the mainland states. Queensland also has high cultural and Indigenous diversity. This presents Queensland with an extra resourcing challenge.

Geographic Diversity – Queensland is Australia's second largest state with large regional cities, rural towns, remote communities and a network of offshore islands. The vast distances and varying accessibility can make it challenging to deliver consistent science engagement programs across the state. While urban areas such as Brisbane have well-developed science infrastructure, regional, rural and remote communities lack similar facilities and resources, making it challenging to deliver high-quality science programs.

Demographic Diversity – Queensland has a rich cultural heritage, with a diverse population including many First Nations communities, Pacifika communities, refugee communities, and culturally and linguistically diverse (CALD) communities. Engaging effectively with these diverse audiences requires targeted approaches, culturally sensitive materials and respect for traditional knowledge and practices.

Economic Diversity – There are significant economic disparities between different regions of Queensland, with some areas facing higher levels of poverty and limited access to internet and educational resources. Addressing the needs of economically disadvantaged communities requires tailored programs and resources to ensure equitable access to science engagement opportunities.

Addressing these unique challenges requires a strategic and localised approach to science engagement supported by appropriate funding and human resource capacity. To maximise resources, the Queensland Government leverages partnerships with local organisations, facilitating programs in collaboration with universities, the school sector, industry, science organisations and community groups. This has both advantages and challenges. By including communities in the co-design of new science engagement programs, design teams ensure alignment of the program with community needs and interest.

1.2 Scope – who will use this document and how?

The approaches outlined in this document will be used by the government and its partners, stakeholders, grant applicants, and industry and community groups as a practical guide for designing, delivering and evaluating community science engagement programs with a proven evidence base.

The individuals and organisations that will benefit from the insights of this document include:

The Queensland Government: This document will enable government departments to assess current and future science engagement programs and serve as a guide to ensure that best practice program design and delivery principles are embedded in government programs, as well as external programs and grant schemes supported by public funding. Additionally, the document may be used to assess and potentially discontinue programs not meeting best practice standards.

Grant Applicants and Recipients: grant applicants seeking funding to support community science engagement can ensure that their proposed programs align to best practice approaches outlined in this document. This will support applicants in designing and delivering programs against set goals and outcomes, enhancing the quality of funding applications and improving success rates. Grant recipients will have clear guidelines for evaluating and reporting outcomes back to funding agencies.

Industry Partners: Industry partners will benefit from clear guidelines for developing programs that align with government priorities, community needs and their own interests. Quality industry-linked engagement programs will support workforce development by raising aspirations in STEM studies and careers, and improve public perceptions by promoting a positive and genuine company brand image.

Scientists: The guidelines will provide scientists with a structured framework to reach and connect with the public in an effective and meaningful way, ensuring their outreach efforts are relevant, accessible, and aligned with community needs. High quality engagement by scientists presents science in an authentic way that in turn promotes public trust and enhances credibility. Standardised evaluation methods allow scientists to evaluate success, further supporting future funding and institutional support for community engagement. For university academics, it provides a structured approach to address their community engagement KPI’s.

Non-Profit Community Organisations: Community organisations have resources, time, and a strong commitment to community engagement. However, they often suffer from a lack discipline expertise, understanding current policy priorities, and the ability to secure sustainable funding. These guidelines help bridge that gap by providing pathways for connecting with educators, scientists, and STEM professionals as well as insights into government and education priorities in STEM. By ensuring programs are informed by current knowledge and best practices, organisations will enhance their credibility, improve access to funding, and contribute meaningfully to broader STEM engagement and educational goals within their communities.

Schools: Schools can use the guidelines to more effectively and efficiently design new programs or evaluate existing STEM programs offered by external organisations, allowing greater justification for school resourcing. The guidelines also provide the rationale and strategies for building connections with scientists, industry partners, and informal STEM learning spaces, enhancing the quality and impact of student learning.

2.0 Methodology and Approach

2.1 General Approach

In developing this report, an initial scoping review of available research literature was carried out to develop an evidence base for best practice approaches to community science engagement. Both peer-reviewed literature and grey literature searches were conducted.

A thematic analysis of the literature allowed identification of a series of common key principles in the design and delivery of successful science engagement programs. With these best practice principles established, the literature was further interrogated to determine:

1) the theoretical foundations behind each principle – outlining the evidence base for *why* each principle is important, and
2) practical implementation of each principle – outlining approaches and examples of *how* best to implement (adopt/adapt) each principle in practice.

2.2 Initial Scoping Review

The purpose of the initial scoping review was to identify:

1) best practice *design* principles for community engagement, in a general sense, and
2) to identify specific best practice *science engagement* principles for community science engagement.

The initial scoping review was informed by standard scoping review frameworks (Arksey & O'malley, 2005) tailoring them to identify principles specifically relevant to best practice '*design*' and *'science engagement'* considerations, in the context of community science (or STEM) engagement programs.

2.2.1 Research questions

The following primary research question was developed for initial scoping review:

- *What are the best practice design principles for community science engagement programs?*

Additional research sub-questions relating to practical design components, common challenges, and program evaluation were developed to assist in focussing the search strategy:

- *What are the fundamental elements of effective program design for community engagement in science?*
- *What strategies enhance accessibility, inclusivity and ongoing participation in community science engagement programs?*
- *What are the common challenges in implementing community science engagement programs, and what solutions have proven effective in overcoming them?*
- *What methods and/or evaluation metrics are used to evaluate success and impact; and what common frameworks can be used to design and assess these programs?*
- *What are examples of best practise that have been developed in Queensland, Australia, or globally?*

2.2.2 Identifying relevant studies

A comprehensive search across the following databases was carried out: Scopus, Web of Science, ERIC and Google Scholar, focussing on combinations of the following keywords: 'community science engagement', 'community STEM engagement', 'science outreach', 'STEM outreach' 'program design', 'program delivery', 'design principles', 'best practice'.

This approach was supplemented by a grey literature search locating relevant reports, evaluations, policy papers, and case studies from, for example, government agencies, non-profit science and education organisations, philanthropic foundations, NGO's, museums, science centres and libraries.

Initial inclusion criteria included:

- peer-reviewed articles, government documents, case studies and published frameworks focussing on science engagement targeting community or public audiences, and
- studies that address design principles or elements, delivery principles or elements, evaluation approaches or frameworks.

Initial exclusion criteria included:

- articles, papers, case studies unrelated to community-based settings (including those related to in-class school settings), and
- programs lacking program design, program delivery and/or program evaluation components.

An initial title and abstract screening process was carried out to identify potentially relevant studies. This was then followed by a full text review.

2.2.3 Thematic analysis and secondary review

A thematic analysis was conducted to:

- Identify common themes related to best practices in program design, including evaluation methodologies, and program delivery strategies.
- Identify existing, widely applicable frameworks for program design and delivery that can be adapted across different contexts, locations, and target audiences.
- Identify practical challenges in implementation and identify strategies to overcome them.

Following the thematic analysis, a secondary review process was undertaken to further refine and enhance the findings. This involved an in-depth examination of the selected studies, specifically focusing on:

- Citation Mapping – references cited within the selected studies were reviewed to identify additional relevant sources. This process helped uncover foundational studies that informed the development of best practice principles.
- Forward Citation Analysis – research papers that had cited the selected studies were examined to track how key concepts had evolved over time and to identify newer contributions to the field.

Rather than aiming for a systematic literature review that could be precisely replicated, the objective was to build a broad evidence base that could meaningfully inform the design and implementation of successful community science engagement programs.

3.0 Overview of Literature Review

The scoping review of peer-reviewed literature identified a set of best-practice principles for designing and delivering effective community science engagement programs. These principles are categorised into two key themes:

- **Best-Practice Core Design Principles** – these are fundamental, non-discipline-specific considerations that underpin the success of any community engagement initiative. Regardless of the specific subject matter, well-designed programs share common characteristics that ensure short term success, long term sustainability, and accessibility/inclusivity.
- **Best-Practice Science Engagement Principles** – while general design principles provide the organisational foundation for designing community engagement programs, science engagement requires specific approaches that promote deeper connections with science concepts, science practices, and the science aspirations of participants.

Best-Practice Core Design Principles

The review identified six core design principles essential for community science engagement programs:

1. Clear, Concise, and Relevant Objectives and Goals
2. Fit-for-Purpose Evaluation Approaches and Methodologies
3. Capacity and Capability
4. Sustainability and Scalability
5. Collaborations and Partnerships
6. Accessibility and Inclusivity.

All are closely linked and inter-related. For example, well-defined objectives and goals provide a foundation for effective evaluation. Similarly, strong collaborations and partnerships enhance capacity and capability by bringing in expertise, resources, and networks that support program sustainability. Accessibility and inclusivity ensure that scalability is meaningful, reaching diverse and underrepresented communities. Collectively, these principles allow for the design, delivery, and evaluation of programs that are both impactful and enduring. Best practice *core design* principles are explored in detail in Chapter 4 of this document.

Best-Practice Science Engagement Principles

In addition to core design principles, the review identified seven key principles specific to science engagement:

1. Incorporate Inquiry-Based Learning Approaches
2. Hands-on Experiential Learning – Investigations and Experiments
3. Engage Relatable Scientists
4. Influence the Influencers
5. Utilise Informal Learning Spaces
6. Connect with Formal Education
7. Leverage Local Content, Context and Resources.

Of significance here is the alignment of these engagement principles to the concept of 'science capital', encompassing not just scientific knowledge but also the broader cultural, social and personal factors that influence an individual's engagement with, and attitudes toward, science.

Best-practice science engagement principles seek to increase the science capital of individuals by not only addressing scientific understandings but also ensuring that science experiences are relatable, accessible and relevant. The relevance of science capital to the best-practice principles is discussed in Chapter 3.2 below. Best practice *science engagement* principles are further examined in Chapter 5 of this document.

3.1 Science Engagement – what is it and why do it?

Outcomes from the initial scoping review revealed the importance of first understanding exactly what is meant by 'science engagement' and why we should do it. The scoping review also highlighted the importance of clearly articulating the purpose and value of community science engagement efforts.

3.1.1 Science engagement – what it is, and what it isn't

Engagement is, by definition, a two-way process, involving interaction and communication, with the goal of generating mutual benefit, at the least, and ideally creating new value and new knowledge and understandings together.

For this study, science engagement refers to the collaborative effort between scientific professionals or educators and members of the public to share, discuss, and co-create new knowledge and/or scientific understanding. This concept goes beyond the mere one-way communication of scientific facts or ideas; it involves building a two-way dialogue that enables the public to participate actively in scientific practice or science discourse, thereby developing trust, understanding, and an appreciation of science (Gauchat, 2011).

By contrast, traditional forms of science communication (e.g. through documentaries and science magazines etc.) do not constitute a form of science engagement for this study. Science communication of this nature typically focuses on a one-way sharing of scientific knowledge, discoveries, and concepts with a broad audience. It involves translating complex scientific information in ways that are clear, accessible, and understandable for non-experts, using story-telling approaches, visuals, and other relatable methods.

In summary, science communication (as described above) involves one-way sharing of information to inform and educate; whereas science engagement involves two-way interactions to connect, involve, create and empower.

3.1.2 Science engagement – why do it?

The motivations for community engagement in science involve several overlapping, yet distinct, drivers that can be broadly categorised as instrumental motives, practical motives and social motives. Each category represents different underlying purposes for promoting and delivering science engagement activities within the broader community.

Instrumental Motives: Instrumental motives focus on achieving specific outcomes that benefit the scientific community or policy agendas. These motives are often oriented toward nurturing support for scientific research, increasing public understanding, or encouraging behaviours that align with scientific recommendations (Davies, 2013; Weingart et al., 2021; Wynne, 2006) (Gauchat, 2011). Instrumental motives can be characterised by:

Building Public Trust – which can be crucial during times of crisis or for issues that require public cooperation, such as vaccination programs or remediation actions.

Policy Support – Engaging communities can generate support for science-based policy decisions, ensuring policies have a stronger foundation of public backing.

Improving Funding and Resources – By showing societal relevance, science engagement activities can attract funding, maintain political support, and justify resource allocation.

Practical Motives: Practical motives are rooted in the operational benefits that community engagement brings to scientific research and practice. Engaging with communities often provides scientists with local knowledge, boosts participation in data collection, and creates a more inclusive scientific process (Bonney, Ballard, et al., 2009; Bonney, Cooper, et al., 2009; Bonney et al., 2014; Eitzel et al., 2017; Stilgoe et al., 2014). Practical motives can be characterised by:

Data Collection and Contribution – In initiatives like citizen science, community members assist with data collection, enabling researchers to gather large datasets that would be difficult to obtain otherwise.

Access to Local Knowledge – Community engagement allows scientists to gain insights from individuals with unique local knowledge, particularly in fields like environmental science and conservation.

Enhancing Research Relevance – By involving communities, researchers can align their work with public interests and needs, ensuring the outcomes are more applicable and useful to society.

Social Motives: Social motives focus on broader societal goals, such as empowering citizens, improving scientific literacy, and supporting democratic participation. Often referred to as a normative commitment to community engagement, these motives goes beyond the practical benefits of engagement, such as improving scientific literacy, and emphasises the intrinsic responsibility to make science accessible, equitable, inclusive, democratic, and responsive to societal needs and values (Besley, Dudo, Yuan, et al., 2018; Stilgoe et al., 2014; Weingart et al., 2021). Social motives (or a normative commitment) for science engagement can be characterised by:

Promoting Science Literacy and Critical Thinking – Community engagement helps build science literacy, empowering citizens to understand scientific issues and make informed decisions.

Democratising Science – A social motive for community engagement is to democratise science by involving diverse voices and perspectives, ensuring that scientific research reflects the values and concerns of the broader community.

Social Equity and Inclusion – Social motives also include addressing inequities in access to scientific knowledge and opportunities, actively engaging underrepresented communities in science. By promoting inclusivity, science engagement helps ensure that all segments of society can benefit from scientific advancements.

3.2 The Importance of Science Capital

Common themes in the scoping review that characterise best-practice science engagement include incorporation of practices that allow individuals to:

- improve their scientific literacy
- increase their engagement in formal and informal science learning
- improve their aspirations for STEM careers; and
- connect to relevant, real-world contexts.

Engaging with these practices is largely encapsulated by the concept of science capital.

Science capital refers to the set of resources, knowledge, skills and experiences that individuals accumulate through their interactions with science in their daily lives. It plays a key role in shaping an individual's engagement with, and participation, in STEM education and STEM related careers. It is based on the idea that individuals from different backgrounds bring various forms of 'capital' (knowledge, networks, practices, attitudes etc.) to their engagement with science, and this capital can significantly influence their opportunities and willingness to participate and succeed in science.

The concept of science capital emerged from the ASPIRES projects (Archer et al., 2023; Archer et al., 2020; Ker et al., 2013) – an ongoing series of large-scale, longitudinal studies, tracking the STEM motivations and aspirations of young people in the UK. These studies have provided significant insights into the factors that shape attitudes toward STEM, specifically revealing that students with higher levels of science capital (often stemming from family background, educational exposure, and access to resources) were more likely to be motivated by STEM and develop aspirations for STEM studies and careers.

Conversely, students with lower science capital (particularly those in underrepresented groups) often developed a sense of disconnection from science, manifesting in lack of engagement with STEM. These findings align with Australian (YouthInsight, 2022(a), 2022(b), 2023) and international studies (Marotto & Milner-Bolotin, 2018; Milner-Bolotin & Marotto, 2018; Van Tuijl & van der Molen, 2016) that show familial support and exposure to science in everyday life are key factors in promoting interest and aspirations in STEM studies and careers.

These ideas on science capital have been further developed over the last decade through a series of studies from researchers at University College London (Archer et al., 2015; Archer & Dewitt, 2015; Archer et al., 2012b; DeWitt et al., 2016; DeWitt et al., 2014) and others (Jones et al., 2022; Kontkanen et al., 2024), and have been extended to community science engagement programs (Cavalcante & Gonsalves, 2021; DeWitt & Archer, 2017; Tran et al., 2024; Zivtins, 2022). This research has identified eight dimensions of science capital which fit into four overarching components as shown in Table 3.2.1.

Table 3.2.1 Dimensions and Components of Science Capital (Adapted from(Archer et al., 2018))

Dimensions and Components of Science Capital	
Components	**Dimensions**
What You Know: your knowledge about science, the scientific method, and the way science is applied in the real world. **(Dimensions 1 and 3)**	**1. Scientific literacy:** an individual's knowledge and understanding about science and how science works. This also includes their confidence in feeling that they know about science. **2. Science-related attitudes, values and dispositions:** the extent to which an individual sees science as relevant to their everyday life.
How You Think: your mindset regarding science—whether you perceive it as something accessible and valuable or something complex and out of reach, "not for me". **(Dimension 2)**	**3. Knowledge about the transferability of science:** understanding the utility and broad application of scientific skills, knowledge and qualifications. **4. Science media consumption:** the extent to which one engages with science-related media including television, books, magazines and internet content.
What You Do: practical engagement with science through experiences like science fairs, museum visits, experiments or informal science discussions **(Dimensions 4, 5 and 8)**	**5. Participation in out-of-school science learning**: how often an individual participates in informal science learning contexts, such as at science museums, science clubs and fairs. **6. Family science skills, knowledge and qualifications:** the extent to which a person's family have science-related skills, qualifications, jobs and interests.
Who You Know: the people in your network who are involved in science, including family members, mentors, professionals and teachers **(Dimensions 6 and 7)**	**7. Knowing people in science-related roles:** the people an individual knows (in a meaningful way) among their wider family, friends, peers and community circles who work in science-related roles. **8. Talking about science in everyday life:** how often an individual talks about science with key people in their lives (e.g., friends, family members, neighbours, community members).

The eight dimensions shown in Table 3.2.1 are important because they show that barriers to STEM participation are not just about raw academic ability in formal science studies (the dimension of *scientific literacy*), but are deeply influenced by social, cultural, and familial contexts. Understanding these influences is critical to addressing disparities in STEM engagement, particularly for underrepresented groups.

Understanding these dimensions is also crucial for designing effective community science engagement programs to address barriers to STEM participation and to create inclusive and effective initiatives that not only enhance scientific literacy and critical thinking, but also engender a sense of belonging in science (Archer et al., 2023; Archer et al., 2020; Ker et al., 2013).

3.2.1 Science capital as a rationale for community science engagement

Community science engagement programs aim to increase public participation in STEM, improve scientific literacy and critical thinking skills, and promote positive attitudes towards science to increase the pipeline of STEM studies and STEM careers. However, individuals do not engage with science equally – barriers related to social background, education, family influence, and societal norms limit participation for many groups, particularly those from underrepresented backgrounds (Archer et al., 2012b; Tran et al., 2024). For example, studies have shown that *"household income remains the strongest predictor"* of children's participation in extracurricular STEM programs (Xu et al., 2009).

By adopting a science capital approach, community science programs can:

- **Recognise barriers to STEM participation:** People with lower science capital (e.g., limited science-related knowledge, experiences, or role models) and lower SES backgrounds are less likely to see science as "for them" and therefore less likely to participate in community science programs.
- **Acknowledge the role of social and cultural factors:** Science engagement is not just about knowledge acquisition but also about identity formation – how people perceive themselves in relation to science. Adopting a science capital approach ensures that community engaging initiatives focus on building long-term interest and confidence in STEM, rather than just delivering one-off experiences.
- **Promote equity and inclusion:** Instead of assuming all individuals start with the same level of exposure to science, programs can be designed to specifically support those with lower science capital, ensuring engagement efforts benefit diverse communities.

3.2.2 Science Capital – a framework for designing and implementing community Science Engagement

Adopting a Science Capital approach to designing and delivering community science programs offers a holistic, equity-focused approach to community science engagement. By addressing knowledge, attitudes, participation, and social connections, programs will create meaningful and sustained engagement in STEM, particularly among groups that traditionally have lower participation rates.

To effectively design and implement community science engagement initiatives using a science capital approach, program designers can focus on the four key components of science capital, linking them to key design principles, as shown in Table 3.2.2.

Evaluating Science Capital

In addition to designing programs aligned to science capital, program organisers should consider pre- and post-evaluations of science capital. Assessing the existing science capital of participants will ensure that science engagement programs meet the needs of the intended audience(s). Post-program evaluations can show measurable changes in key aspects of science capital including changes in beliefs, practice, attitudes, knowledge and development of networks. Evaluation approaches are considered in detail in Chapter 4.2.

Table 3.2.2 A Science Capital Framework for Designing Community Science Engagement Programs

Science Capital Component	Features of Community Engagement	Science Engagement Principle Addressed in this Report
What You Know Addressing scientific literacy and critical thinking skills, facilitating a knowledgeable STEM pipeline	Programs should increase understanding of science concepts and science practices by incorporating well-established, evidence-based inquiry and hands-on experiential learning approaches, tailored to match audience knowledge and skills – thereby building confidence and understanding as well as making science more relevant to everyday lives.	1. Adopt Inquiry Based Learning Approaches (Chapter 5.1) 2. Incorporate Hands-on Experiential (Chapter 5.2) 6. Connect with Formal Education (Chapter 5.6)
How You Think Addressing science-related attitudes and values; elevating appreciation of science	Programs should address stereotypes, misconceptions and personal value of science, science studies and science careers – promoting the relevance of science and a mindset that science is "for me".	3. Engage Relatable Scientists (Chapter 5.3) 4. Influence the influencers (Chapter 5.4)
What You Do Addressing engagement *in* and *with* science	Programs should consider extracurricular engagement in science by embedding experiences in informal learning settings such as museums, science centres, libraries, makerspaces and by leveraging existing networks (faith groups, sports clubs, youth centres) to embed STEM engagement into familiar contexts. Ideally, these experiences should be ongoing, rather than one-off experiences – thus normalising STEM exposure.	3. Engage Relatable Scientists (Chapter 5.3) 5. Utilise Informal Learning Spaces (Chapter 5.5) 7. Leverage Local Context and Local Resources (Chapter 5.7)
Who You Know Addressing science-related social capital by directly influencing, and widening the scope of, influencers and role models	Programs should: encourage family and community participation (rather than just focusing on students/children; expand the networks of scientists and STEM professional available to participants; and encourage mentoring opportunities by appropriate role models.	3. Engage Relatable Scientists (Chapter 5.3) 4. Influence the influencers (Chapter 5.4) 7. Leverage Local Context and Local Resources (Chapter 5.7)

4.0 Best Practice Core Design Principles

This study has identified the following set of six core, foundational principles considered fundamental for the design of successful community science engagement initiatives.

4.1 Clear and Relevant Goals and Objectives

This principle emphasises that successful community engagement programs must have a well-articulated purpose and well-defined outcomes that guide its design, delivery, and evaluation. Without clear goals and objectives, it is difficult to assess a program's impact or ensure that resources are used efficiently.

Clear goals and objectives provide a strategic direction for the program and ensure that all stakeholders (including participants, facilitators, organisers, and funders) have a shared understanding of what the program aims to achieve and how it aims to achieve it.

GOALS VS OBJECTIVES: The difference between goals and objectives lies in their scope, specificity, and their capacity to measured. Goals are broad, long-term aspirations that define what you ultimately want to achieve. They are generally linked to an overarching purpose, vision or mission and provide the general long-term direction of a program. They are typically articulated in a qualitative sense – i.e. not specifically measurable). A broad goal can be met by one or more objectives.

By contrast, objectives are specific, measurable targets/actions articulated to achieve a goal. They are short- to-medium-term, time-bound, and practically actionable. Objectives are met by carrying one or more specific activities or tasks that generally involve engaging with participants.

In short, goals define the bigger picture destination, while objectives outline the roadmap to get there.

4.1.1 Why articulate goals and objectives

Research over the past 90 years confirms goal-setting as a universal method for improving performance and outcomes for organisations and programs across a wide range of disciplinary fields (Locke & Latham, 2019). Key take aways from *Goal-Setting Theory* are outlined below.

CHALLENGE: Clear goals and specific objectives that are challenging improve outcomes compared to vague or easy goals/objectives (Locke & Latham, 2002). People are more motivated, more persistent and perform better when clear, challenging goals and objectives are set. However, while goals/objectives should be ambitious and challenging, they need to be attainable and realistic to maintain motivation and engagement.

COMMITMENT: Well-articulated goals and objectives should align to needs and wants of all stakeholders including participants, presenters, organisers and funders. Individuals are more likely to achieve goals they are personally committed to and motivated for .... *"those pursuing self-concordant goals put more sustained effort into achieving those goals and are more likely to attain them – they further reap greater well-being benefits from their attainment"* (Sheldon & Elliot, 1999). People are also more likely to sustain effort toward goals when those goals align with their personal values and long-term aspirations (Deci & Ryan, 2000).

Successful programs should therefore involve all stakeholders in goal-setting discussions to increase commitment – including community input to ensure that goals/objectives resonate with local priorities.

ACCOUNTABILITY: when people share their goals and objectives with others, or publicly commit to them, they are more likely to persist and succeed (Frink & Ferris, 1998). Many programs therefore use public pledges, group commitments, or share progress evaluations to boost accountability.

RESOURCING: Clearly defined objectives minimise wasted time, effort, and money by focusing activities on agreed-to measurables, aligned to big picture goals.

EVALUATION: Well written goals and objectives articulate criteria for success, enabling systematic assessment of impact. Program evaluations are an essential component of any community engagement program and should provide an analysis of impact for all stakeholders. Well-written goals and objectives lay the foundation for meaningful evaluation, ensuring programs stay on track. The next chapter (Chapter 4.2) explores program evaluation approaches in detail, and how they can contribute to the development of even more effective initiatives. If available, such evaluation reports should be considered during the initial design phase.

SUSTAINABILITY: Research shows that long-term goal setting is essential for transitioning from pilot phases to broad implementation, and for securing sustained funding. Chapter 4.4 explores program sustainability approaches in detail.

4.1.2 How to write and articulate goals and objectives

Example

Goal: *Engage and inspire regional and remote Darling Downs communities in STEM to enhance senior school studies in maths and science*

Objectives:

1. Increase STEM Participation – *Deliver interactive science workshops and demonstrations to 80% of schools in the Darling Downs region over the next three years, focussing on Year 7-9 students to encourage continued STEM education.*
2. Enhance STEM Career Awareness – *Organise career talks and mentorship sessions featuring STEM professionals from academia and industry, ensuring that at least 50% of participating students report increased awareness of STEM-related career pathways.*
3. Support Educators and Schools – *Provide professional development workshops for at least 30 regional and remote teachers annually, equipping them with resources and strategies to sustain STEM engagement beyond the program's direct interactions.*
4. Engage and Influence Parents – *Host STEM-focused family engagement events and provide accessible resources that empower parents to support their children's interest in STEM, aiming for at least 60% of parents to report increased confidence in discussing STEM topics.*
5. Promote Equity and Accessibility –*STEM participation events will target underrepresented groups, including Indigenous students, girls in STEM, and students from low-SES backgrounds, ensuring at least 40% of program participants come from these groups.*

WRITING GOALS: Goals are broad – they describe the overall desired outcome, often with a focus in a particular direction or improvement area. The goal statement in the example above is big picture, aspirational and long term. Some tips for writing goal statements include:

- Align your goals with your organisational or program priorities – ensure you align it to any broader mission or vision statement your organisation may have.

- Keep your goals broad and aspirational – they should reflect the overarching purpose.
- Make your goals clear, inspiring and ambitious – they should be easy to understand and motivate action.
- Use action-oriented language – start with strong verbs like *enhance, improve, promote, increase (or decrease), develop, support.*

WRITING OBJECTIVES: Objectives break down a goal into specific, measurable, and actionable steps that define how success will be achieved. Unlike goals, which are broad and aspirational, objectives should be concrete and provide a clear roadmap for implementation and evaluation. Some tips for writing objectives include:

- Ensure alignment with your goal statement – your objectives should directly support your broader goal and align with your program's overall purpose.
- Clearly define success – your objectives should articulate what will be accomplished and how success will be measured. For example, in Objective 5 above, instead of saying *"ensure participation of underrepresented groups"* we have specified *"ensure at least 40% participation comes from these groups".*
- Use action-oriented language – like your goal statement, begin your objective statements with strong verbs like *develop, implement, expand, increase, decrease, evaluate, enhance.*
- Consider stakeholders – effective objectives address different stakeholder groups, including participants, educators, parents, community members, collaborators and funders, ensuring widespread buy-in and impact.
- Follow well established criteria protocols – for example writing objectives using the SMART criteria will ensure your objectives are *Specific*, *Measurable*, *Achievable*, *Relevant*, and *Time-bound*. Others include PACT (*Purposeful*, *Actionable*, *Continuous*, *Trackable*) and HARD (*Heartfelt*, *Animated*, *Required*, *Difficult*).

BRIEF SUMMARY OF CRITERIA FOR WRITING OBJECTIVES: SMART criteria (Doran, 1981) are the most common framework adopted for writing objectives**:**

- *Specific* – Objectives should be clear, precise, and well-defined.
- *Measurable* – Objectives must include criteria to track progress and define/assess how success will be tracked (quantitative or qualitative).
- *Achievable* – Objectives should be realistic and achievable – ensure feasibility within resources and constraints.
- *Relevant* – Objectives should align with the goals and broader strategy of your organisation.
- *Time-bound* – Objectives need a clear deadline or timeframe; this prevents delays and keep efforts focussed.

Along similar lines, McDavid and Hawthorn (McDavid et al., 2018)(p.64) propose that ideal program objectives should have at least four characteristics:

- They should specify the target population/domain over which the expected program outcomes should occur.
- They should specify the direction of the intended effects – that is positive or negative change.
- Specify the timeframe over which the changes will occur.
- They should specify the magnitude of the change and be measurable.

ADDITIONAL RESOURCES: Articulating goals and objectives is a key starting point for overall program design. **Appendix A** provides a range of additional resources to assist with overall program design for community science engagement programs. Subsequent appendices provide more specific resources for each of the specified core design principles and science engagement principles.

4.1.3 Case study – application of goal setting theory

The following is extracted from (Latham, 2004).

The American Pulpwood Association was searching for ways in which pulpwood producers, that is, independent loggers, could increase their productivity (cords per employee hour). The majority of the employees were uneducated, unskilled laborers (sic) *who were paid on a piece-rate basis. Cutting pine trees in the southern United States can be tiring, monotonous work. Based on goal-setting theory, pulpwood crew supervisors assigned a s specific high goal, gave out tally meters to enable people to keep count of the number of trees that they cut down, and then stood back and watched.*

The people who were assigned goals started bragging to one another as well as to family members as to their effectiveness as loggers. Productivity soared relative to those crews who were urged to do their best. Goal-setting instilled purpose, challenge, and meaning into what had been perceived previously as a tedious and physically tiresome task. A by-product of the goal intervention was that within the week, employee attendance soared relative to attendance in those crews who were randomly assigned to the condition where no goals were set. Why? Because the psychological outcomes of setting and attaining high goals include enhanced task interest, pride in performance, a heightened sense of personal effectiveness, and, in most cases, many practical life benefits such as better jobs and higher pay.

What is wrong with urging people to "do their best," especially when they are paid on a piece-rate basis? The answer is that people simply do not do their best because this exhortation is too vague, too abstract. There is no external referent for evaluation. Consequently, it is defined idiosyncratically. It allows for a wide range of performance levels that are acceptable to different people. Setting a specific high goal, on the other hand, makes explicit for people what needs to be attained.

4.2 Fit-for-Purpose Evaluation Approaches and Methodologies

“If you can’t measure it, you can’t improve it.” **Women in STEM Decadal Plan** (p. 23) (AAS, 2019)

This principle recognises the importance of measuring the impact and effectiveness of community science programs against goals, objectives and intended outcomes for participants and other stakeholders. Done well, program evaluations enhance participant experiences, promote accountability and transparency, contribute to ongoing sustainability, future funding and institutional support as well as guiding the design of future engagement activities for greater impact and success.

Evaluation of community science programs typically assess changes in participants’ beliefs, practices, behaviours, and aspirations related to STEM, as well as levels of engagement and enjoyment during participation. Additionally, understanding gains in scientific knowledge, practical skills, and inquiry skills are typical measures for science engagement programs.

Where possible and where appropriate, evaluation approaches should also be inclusive and participatory, ensuring that all stakeholders (including funders, organisers, and facilitators) are actively involved in assessing the program's effectiveness – thereby accounting for the different interests and desired outcomes of each stakeholder group.

Finally, evaluations should ideally include up-front (pre-program) assessment of program design and ongoing formative evaluations, enabling continuous refinement and improvements *during* program delivery, rather than relying solely on a final summative assessment at the end of the program.

4.2.1 Why carry out program evaluations?

There are two simple reasons for conducting evaluations of community science engagement programs (Frechtling, 1997):

1. to gain insights for improving programs as they are developing, and
2. to determine programs' effectiveness after they have had time to produce results.

More specifically, program evaluations help to:

- ensure that initial program design aligns to best practice principles
- validate program effectiveness against articulated goals, objectives and intended outcomes/outputs
    - for example, justify the need for and what impact delivering the program will have in the targeted community
- improve participant experiences during the program
    - for example, through ongoing formative evaluations
- provide feedback to all stakeholders that are aligned to their needs, wants and motivations (including participants, organisers, facilitators and funders)
- deliver on accountability and transparency concerns
    - for example, detailed program evaluations are generally a requirement for organisations that fund and/or support community programs
- enhance sustainability, scalability and future funding opportunities
    - for example, many (most?) successful science engagement programs start small, with a pilot program, to establish a track record of success, leading to future funding and institutional support, facilitating sustainability and scalability.

EVALUATING OUTPUTS, OUTCOMES AND IMPACTS: When evaluating community science engagement programs, it is important to distinguish between *outputs*, *outcomes*, and *impacts*, as each represents a different level of assessment and different level of insight into program effectiveness.

Outputs (immediate and measurable deliverables): Outputs refer to the tangible, direct results of engagement activities. These are the easiest to measure and largely within the control of the program organiser. Outputs typically include measures such as the number of participants, number of events held, bookings taken, materials distributed, or social media reach. While outputs provide an indication of activity levels and program reach, they do not necessarily reflect whether meaningful change has occurred.

Outcomes (short- to-medium-term effects on participants): Outcomes go beyond participation numbers to assess the immediate or intermediate changes resulting from engagement. These may include increased knowledge, shifts in attitudes/beliefs/aspirations, skill development, behavioural changes or access to new STEM opportunities and networks (Owen, 2020).

Unlike outputs, which focus on what was *done*, outcomes examine what was *achieved* because of the engagement process. Measuring outcomes often requires surveys, interviews, or follow-up assessments to track changes in perception or behaviour.

Impacts (long-term and broader societal changes): Impacts represent the most significant and lasting effects of engagement efforts, often occurring at a community or societal level. These can include policy changes, increased public trust in science, long-term shifts in environmental practices, or strengthened relationships between scientists and the community. Impacts are generally more difficult to measure and may require long-term tracking and evaluation.

While outputs are the easiest to measure, they are the least indicative of real change. Outcomes provide more insight into participant engagement and learning, but they require additional evaluation methods. Impacts, though the most meaningful, are the hardest to assess due to their long-term nature and external influencing factors. A comprehensive evaluation approach should track all three levels to ensure that community science engagement programs are not only reaching people but also creating meaningful and lasting change.

Aligning Evaluation Approaches to Program Goals and Objectives: A survey of Australian STEM outreach programs (Husher, 2010) showed the following top 5 goals for outreach:

- Encourage pursuit of science careers or studies
- Inspire interest, engagement or enthusiasm
- Promote science
- Encourage participation in science
- Support science teaching in schools.

However, the results of the same survey showed "*a concerning misalignment between (overall) program goals and objectives, and program evaluation objectives and performance measures*" … and … "*very few programs appear to have drawn on their overall program goals when outlining the objectives for their evaluation*".

An international review of publications relating to community-university collaborations found a similar outcome, with only 13 papers (of 150 reviewed) describing program evaluation approaches that went beyond individual descriptions of specific projects and that might be transferable to other situations (Hart & Northmore, 2011). Problems in measuring outcomes and impact in university–community engagement include: a lack of focus on outcomes; a lack of standardised instruments and tools; and the variety of approaches currently being adopted (Anderson et al., 2019; Kirsten Sadler et al., 2018).

This has led to calls for a common 'evaluation standard' to provide tools and guidance for evaluating community engagement and driving good practice (Reed et al., 2018) – including approaches outlined in the following section.

4.2.2 Implementing program evaluations

Evaluating a community science engagement program requires a structured approach that assesses its design, implementation, and outputs/outcomes/impact. The first step is to develop an *evaluation plan*; this will ensure close alignment of program goals to evaluation approaches and inform other considerations such as *when* to evaluate, *what* to evaluate, *who* to evaluate, and *which* specific methods of evaluation should be adopted.

Establishing an Evaluation Plan: Developing an evaluation plan should be seen as developing a roadmap for program success. Table 4.2.1 provides a very useful template for creating an evaluation plan. The template allows program designers to develop evaluations based around three domains, namely *Program Design*, *Early Program Outputs and Outcomes*, and *Program Impacts*.

To simplify evaluation for practitioners, the planning template below prioritises clarity over rigid academic distinctions between outputs, outcomes, and impacts, ensuring a more accessible and practical approach to evaluation planning (Reed et al., 2018).

Each evaluation domain shown in Table 4.2.1 is briefly considered below.

Table 4.2.1 Community engagement evaluation planning template (adapted from (Reed et al., 2018))

Domain	Questions to ask; points to consider		
Program Design	**Have you evaluated the design of your public engagement?**		
	Does the design follow good practice, underpinned by sound ethics?	Have you systematically identified relevant stakeholders?	
		Do you understand the expectations and specific benefits each group is likely to derive from engagement?	
		Have you identified and made contingencies for any risks and assumptions?	
		Have you tested your activities and sought feedback from relevant stakeholders?	
	How well do you know the context you are working in, and have you adapted the design of your activities to this context?	Do your proposed engagement activities match the interests and needs of your stakeholders and their social and cultural context?	
		Is there past experience of engagement and existing trust between members of your team and stakeholders?	
		Do you have sufficient resources and support for engagement in your particular context, e.g., professional facilitation, event planning, online delivery etc.?	
Early Outputs and Outcomes	**What immediate outputs and outcomes do you want to deliver from engagement?**	**How will you know you delivered these outputs?**	**What tool will you use to track your progress?**
		Identify indicators to show whether your delivery of engagement activities is providing the immediate outcomes you want.	Identify evaluation tools that will enable you to track the indicators you have identified.
Impact	**What benefits or impacts do you want to achieve from engagement?**	**How will you know you achieved these impacts?**	**What tool will you use to track your progress?**
		Identify indicators to show whether your public engagement is leading to benefits or impacts.	Identify evaluation tools that will enable you to track the indicators you have identified.

Evaluating Program Design: Many common pitfalls in community engagement can be avoided through early, front-end, pre-evaluation of program design. Assessing program design using the template above (and assessing against the best practice principles described in this document) ensures activities are aligned with intended goals, are contextually appropriate, and ethical. If the evaluation of program design is done *prior* to engagement, it allows for necessary improvements to be made in advance.

Evaluating Program Delivery and Early Outputs and Outcomes: Real-time evaluation of program delivery components (such as event attendance, engagement levels, and facilitator feedback) allows for immediate assessment and adjustments to ensure the program is running smoothly and meeting its intended objectives. Tracking these metrics in real time helps identify potential issues early, enabling organisers and facilitators to make necessary improvements during program delivery.

However, successful engagement is not just about program outputs, but also the quality of interactions. Early evaluation of tangible outcomes should also be included, such as measures of increased understanding, increased awareness or behavioural changes.

Evaluating Program Longer Term Impacts: Assessing longer-term outcomes and impact requires measuring benefits beyond the immediate engagement. Impacts may be instrumental (such as building trust, raising awareness or facilitating policy changes), or social (such as promoting scientific literacy, critical thinking, equity and inclusion). Follow-up evaluation after project completion helps capture these effects.

An effective evaluation plan will guide decision-making regarding *when*, *what*, and *who* to evaluate, as well as the best methods to use – all of which are covered in the following sections.

WHEN TO EVALUATE: There are typically three key stages of program evaluation (NASM & National Academies of Sciences, 2016):

- **front-end evaluation** (pre-evaluation *before* program delivery)
- **formative evaluation** (ongoing assessment *during* delivery), and
- **summative evaluation** (post-program impact assessment conducted immediately *after* delivery and at *later* time intervals).

Each stage plays a crucial role in ensuring that engagement efforts are meaningful, effective, and responsive to participant and stakeholder needs.

Front-End Evaluation (Pre-Evaluation): Before launching a public engagement initiative, it is prudent to conduct a front-end evaluation to ensure the program is well-designed and aligned with the needs, context and interests of all concerned. This stage involves systematically identifying relevant stakeholders, understanding their expectations, and clarifying the specific benefits they may gain from participation.

A well-structured pre-evaluation also considers potential risks and assumptions that could influence the program's success. Gathering baseline science capital data—such as attitudes and aspirations, prior science knowledge, and engagement history—helps in tailoring activities that are both relevant and impactful. Additionally, testing or piloting engagement activities before full implementation allows for early feedback and refinement, ensuring that the program is positioned for success.

Formative Evaluation (Ongoing Assessment During the Program): As the program unfolds, formative evaluation plays a critical role in assessing its effectiveness in real-time. This stage focuses on monitoring whether engagement activities are being delivered as planned and whether they are resonating with participants.

Tracking immediate outputs, such as participation levels, audience interactions, and initial feedback, helps to identify what is working well and what may need adjustment. Regular data collection through surveys, interviews, or observational methods enables facilitators to adapt activities dynamically, ensuring that the program remains engaging and responsive to participant needs.

Summative Evaluation (Post-Program Impact Assessment): At the conclusion of the program, summative evaluation is essential to measure its short-term effectiveness and long-term impact. This stage assesses whether the engagement initiative achieved its intended goals and objectives, and whether meaningful changes have occurred among participants. Evaluating success requires identifying key indicators of impact, such as shifts in attitudes and aspirations, increased scientific literacy, behavioural changes, or strengthened relationships between scientists and participants. Tools such as follow-up surveys, in-depth interviews, case studies, and social media analysis help in capturing these long-term outcomes.

Reflecting on the program's strengths and challenges provides valuable insights for future engagement, ensuring that lessons learned contribute to the development of even more effective initiatives in the future.

***Reporting and communication*:** A final consideration is to determine how the information garnered from evaluations will be communicated, to whom and when. Front-end evaluations and formative evaluations are likely to be brief reflective tools, summarising opportunities identified, and challenges overcome. In contrast, summative evaluations may involve a longer formal report requiring a greater emphasis on measurements of outcomes and impact – both short and long term.

WHO AND WHAT TO EVALUATE?: Evaluating community science engagement programs requires gathering different types of information from multiple stakeholders, as each will have unique interests, perspectives, needs and wants.

What to evaluate: As noted previously, evaluating the outcomes and impacts of community science engagement programs generally involves measuring changes in understandings, practices, beliefs, behaviours and aspirations of participants. In developing a framework for evaluating the impacts of informal science education programs, a seminal US National Science Foundation report (Allen et al., 2008), identified a standard set of five impact categories to systematically measure program level outcomes, namely:

- Awareness, knowledge or understanding
- Engagement or interest
- Attitude
- Behaviour
- Skills.

This framework has subsequently informed the evaluation various community science engagement programs, including a range of science outreach programs (Hussar et al., 2008) and citizen science programs (Ballard et al., 2024; Phillips et al., 2018).

Interestingly (and perhaps not surprisingly) this framework aligns closely with the four components and eight dimensions of the science capital framework, as demonstrated in Table 4.2.2.

Table 4.2.2: Alignment of Science Capital framework with Friedman Evaluation Framework (Adapted from (Archer et al., 2018) and (Allen et al., 2008))

Science Capital	Friedman Evaluation Framework
What you know: knowledge about science, the scientific method, and the way science is applied in the real world	**Knowledge**, awareness, understanding: Measurable demonstration of assessment of, change in, or exercise of awareness, knowledge, understanding of a particular scientific topic, concept, phenomena, theory, or careers central to the project. **Skills** related to science inquiry: Measurable demonstration of the development and/or reinforcement of skills, either entirely new ones or the reinforcement, even practice, of developing skills
How you think: mindset regarding science—whether you perceive it as something accessible and valuable, or something complex and out of reach, "not for me".	**Attitudes** toward science: Measurable demonstration of assessment of, change in, or exercise of attitude toward a particular scientific topic, concept, phenomena, theory, or careers central to the project or one's capabilities relative to these areas. Attitudes refer to changes in relatively stable, more intractable constructs such as empathy for animals and their habitats, appreciation for the role of scientists in society or attitudes toward stem cell research
What you do: Practical engagement with science through experiences like science fairs, museum visits, experiments, or informal science discussions ***Who you know:*** The people in your network who are involved in science, including family members, mentors, teachers, and professionals	**Engagement**, interest or motivation in science: Measurable demonstration of assessment of, change in, or exercise of engagement/interest in a particular scientific topic, concept, phenomena, theory, or careers central to the project. **Behaviour**: Measurable demonstration of assessment of, change in, or exercise of behaviour related to a STEM topic. Behavioural impacts are particularly relevant to projects that are environmental in nature since action is a desired outcome

These two frameworks (the science capital model and Friedman's impact categories) serve as valuable guides for designing and evaluating community science programs. Relevant elements from these frameworks should be incorporated into pre-, during-, and post-program data collection for participants as well as other key stakeholders as appropriate. The following provides more detailed guidance on what to evaluate for each major stakeholder group.

Who to Evaluate: Four key stakeholders are identified as being common to most science engagement programs:

- Participants – including students/children, parents, educators, and the general public
- Facilitators – including scientists, STEM professionals, educators, volunteers, workshop leaders
- Organisers – including program coordinators or science engagement managers, community and industry groups/partners, and institutions such as museums, science centres, universities, and government agencies
- Program funders and supporters – including government agencies, philanthropic organisations, industry partners, and universities.

Participants: For participants, as noted above, key evaluation measures should include outcomes measured against outcomes from established frameworks, such as the four components (and eight dimensions) of science capital or Friedman's evaluation framework for informal science. In the Queensland context, this could include outcomes measured against the goals outlined in Chapter 1.

Evaluating against such frameworks may involve assessing changes in

- scientific understanding, scientific literacy and critical thinking skills (what they know)
- beliefs – including attitudes and aspirations toward STEM studies and careers (how they think)
- practices, including the extent and nature of participation in STEM activities – both within and subsequently beyond program engagement (what they do), and
- STEM networks that participants engage with (who they know).

These measures reflect program *outcomes*, which can be powerful measures of program effectiveness and *impact*. However, measures of long-term *impact* can only be demonstrated through sustained measures of changes over time – for example, tracking participants over multiple engagements rather than a single experience, or evaluating participants 6-12 months post engagement.

Other measures that could be evaluated for participants include *output* measures of

- Engagement – to what extent did they participate; was it accessible and inclusive?
- Experience – did they enjoy the program; were there enough opportunities to engage with facilitators/peers/friends/role models etc?
- Feedback – what worked well; what could be improved?

Facilitators: For facilitators, key evaluation measures centre on their own performance and to what extent the experience met personal, professional and institutional goals and objectives, for example:

- Effectiveness of program delivery – was the content engaging, relevant and understandable?
- Participant engagement and feedback – how well did participants respond, what could be improved?
- Challenges faced – what logistical, technical, or communication issues arose?
- Personal and professional development – did the facilitators themselves gain new knowledge, skills or insights?
- Institutional goals and objectives – what evidence can the facilitator provide to their own to institution to demonstrate effectiveness and impact?

Organisers: For organisers, key evaluation measures focus on the extent to which all other stakeholder goals/objectives were met and logistical issues relating to program operation and future opportunities, for example:

- Program execution and logistics – did the program run smoothly; were financial and human resources sufficient; were the facilities and location appropriate?

- Goals and objectives – were program *output* targets met (e.g. participants numbers and inclusivity etc.); were intended *outcomes* met for participants, facilitators, funders etc.?
- Stakeholder collaborations and partnerships – reflection of whether the right people/partners were involved; how well did different groups work together?
- Cost-effectiveness – was the program delivered efficiently and within budget; where did the budget blow-out and why; was the program *cost beneficial* as well as being *cost effective* – how is this last point relevant to funders and your own institution?
- Sustainability and scalability – to what extent can the program be expanded or replicated in other communities?
- Inclusive and accessible – what evidence suggests that the program was suitably inclusive and accessible for a range of audiences; were inclusivity targets met?

Funders and supporters: For funders and supporters, key evaluation measures would target cost effectiveness and the extent to which program outcomes address (or enhance) their vision and/or mission priorities, for example:

- Return on investment (ROI) – was funding used effectively?
- Impact and success – what short and long-term changes resulted (or are envisaged); did the program enhance the funder's mission or reputation?
- Equity, diversity and inclusion (EDI) outcomes – did the program reach underrepresented communities?
- Future funding (sustainability and scalability) – is the program worth funding into the future; can insights from the program inform funding to sustain and/or up-scale the program?
- Policy impact – can insights from the program inform future government funding and policy decisions?

HOW TO EVALUATE?: Evaluation approaches can be broadly classified into two categories – qualitative methods and quantitative methods (see Table 4.2.3). Quantitative evaluation methods rely primarily on the collection of numerical data to measure program impact objectively. Using surveys, structured interviews, and statistical analysis, these methods assess participation rates, behavioural changes, knowledge/skill attainment, and overall program effectiveness against articulated objectives. Findings are often presented in charts, graphs, and statistical reports, providing broad and generalisable insights.

Qualitative evaluation methods explore experiences, perceptions, and social dynamics within the community engagement program. Through interviews, focus groups, and observational studies, these methods capture in-depth narratives and contextual insights. The analysis is interpretative, offering detailed and nuanced findings that may not be broadly generalizable but provide a deeper understanding of participant experiences and program impact.

Most studies emphasise the use of a mixed method approach (Frechtling, 1997; Friedman, 2008) combining quantitative measures (such as pre- and post-tests) with qualitative data (such as interviews and observations). This approach supports a more nuanced understanding of program outcomes and provides a more comprehensive evaluation by capturing both measurable outcomes and deeper contextual insights. Quantitative data identifies broad trends and impact, while qualitative findings explore participant experiences and underlying motivations. Combining data sources reduces bias, enhancing the validity of the evaluation process and strengthening the overall conclusions drawn.

Table 4.2.3 Common types of evaluation methods used in community science engagement programs; quantitative tools (top) and qualitative tools (bottom)

Quantitative Tool	Use when you want to…	Groups suited to tool	Less useful when…	Insights valuable to…
Surveys/ Questionnaires	Understand participant satisfaction; gather demographic data; assess perceived learning or engagement levels; collect structured feedback; measure knowledge gain, attitudes or satisfaction over time	Parents; adult participants; older children (with support); organisers; facilitators; funders	Participants have limited literacy, language barriers, or low motivation to engage with evaluation	Organisers (for program improvement); funders (for reporting); partners (impact evidence)
Tests/Quizzes	Measure knowledge or skill development pre/post program (e.g. in structured workshops or school settings to assess STEM knowledge and skills or critical thinking skills)	School-age children; students in formal or semi-formal settings; program organisers	Informal learning environments; drop-in events; or creative/exploratory sessions	Organisers (learning outcomes); facilitators (instructional effectiveness); funders (outcome data)
Polls	Quickly capture opinions, interest levels, or reactions during or after an activity or presentation	General audiences; children (with facilitation); event attendees; facilitators	In-depth insights or trend data is needed; low digital access or technical familiarity	Facilitators (real-time feedback); organisers (engagement trends); presenters (audience response)

Qualitative Tool	Use when you want to…	Groups suited to tool	Less useful when…	Insights valuable to…
Interviews	Gain in-depth understanding of individual experiences, perspectives, or program impact	Parents, adult participants, older children, facilitators, partners, funders	Large participant groups, limited time or resources	Funders (impact stories), organisers (participant experience), partners (collaboration insights)
Focus Groups	Explore shared experiences, gather feedback through discussion, test ideas or materials	Parents, older children, facilitators, collaborators	Difficult to schedule or facilitate diverse groups; risk of dominant voices	Organisers (program design), facilitators (delivery feedback), partners (group dynamics)
Observations	Assess engagement, participation, interactions, and group dynamics in real time	Children, families, general audiences at events or activities	Evaluator bias risk; hard to capture internal thoughts or learning outcomes	Organisers (engagement quality), facilitators (activity effectiveness), Funders (participant reach)
Journaling/ Reflective Diary	Capture personal reflections, learning journeys, emotional responses, or facilitator insights	Facilitators, presenters, older youth, teachers, program leaders	Young children, low-literacy participants, limited motivation for writing	organisers (implementation feedback), facilitators (professional growth), funders (process insights)
Guidelines	Assess performance or progress against clear criteria in a consistent, qualitative way	Students, workshop participants, facilitators, organisers	Unstructured activities, creative exploration, or informal settings	Organisers (program evaluation), facilitators (participant progress), funders (evidence of quality)

Pros and Cons of Developing Bespoke Evaluation Framework and Tools: When designing evaluation frameworks, practitioners must decide whether to develop new, bespoke, approaches (specific to their own program design) or adopt/adapt existing examples. This decision has both advantages and challenges, particularly given that evaluations need to be rigorous and relevant, bit also need to be carried out within the expertise and resource limitations of program designers and their collaborators.

> *"Program evaluation is partly about learning tools and rules to apply to them. But because most evaluation settings offer only roughly appropriate opportunities to apply tools that are often designed for social science research settings, it is essential that evaluators learn the craft of working with round pegs for square holes"* (McDavid et al., 2018).

The benefit of developing bespoke evaluation frameworks and tools is the ability to align closely with the specific goals, audiences, and operational contexts of a program – whereas existing approaches may not fully capture desired outcomes. Bespoke evaluation approaches also promote a sense of ownership over the process and ensures that local, cultural and contextual priorities are addressed.

However, developing bespoke evaluation frameworks and tools is resource-intensive, requiring significant time, expertise, and financial investment – resources that many programs, especially smaller or community-based program, may not have. Other challenges include the difficulty of comparing results across different programs, and the fact that established frameworks and tools have been refined over time to ensure their statistical reliability and validity. McDavid et al. (McDavid et al., 2018) highlight these challenges, noting that *"there are rarely sufficient resources to apply the tools that would yield the highest quality data, but it does not mean that we should stop asking whether and how programs work*".

Given these factors, the most effective approach is often a hybrid model that blends customised approaches with adaptation of existing approaches. This approach allows evaluators to maintain methodological rigor while addressing the unique aspects of their programs.

Ultimately, the goal of evaluation is not to create the "perfect" framework but to develop an approach that provides useful, actionable, and contextually relevant insights. Whether through bespoke design, adaptation, or a combination of both, an effective evaluation framework should balance feasibility and practicality with the need to ensure program goals and objectives are met.

ADDITIONAL RESOURCES: A range of widely used evaluation frameworks and specific evaluation tools are presented in **Appendix B**.

4.2.3 Case study: a Logic Model approach to the hypothetical Darling Downs STEM engagement program

This hypothetical case-study attempts to 'join the dots' between the ideas presented in the previous and current chapters (i.e. Chapters 4.1 and 4.2). The hypothetical program employed here is derived from section 4.1.2 above – i.e., a STEM engagement program in the Darling Downs region of Queensland with an overarching goal to:

> *Engage and inspire regional and remote Darling Downs communities in STEM to enhance senior school studies in maths and science.*

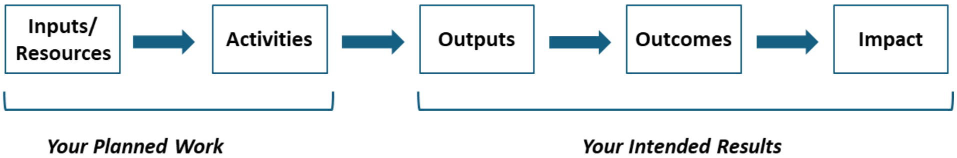
Objective 1 (from section 4.1.2) for this hypothetical STEM engagement program is to:

> *Increase STEM Participation – Deliver interactive science workshops and demonstrations to 80% of schools in the Darling Downs region over the next three years, focussing on Year 7-9 students to encourage continued STEM education.*

The approach adopted for effective program/evaluation design in this hypothetical case study employs the Logic Model Framework, linking program planning, implementation and evaluation.

THE LOGIC FRAMEWORK MODEL: A Logic Model is a structured, visual tool that illustrates the relationships between a program's resources, planned activities, and anticipated outcomes or impacts. It provides a clear framework for understanding how inputs and resources contribute to specific actions and how those actions lead to measurable changes over time (see Figure 4.2.1).

Figure 4.2.1 The basic Logic Model (adapted from (Kellogg, 2004))



By mapping out inputs, activities, outputs, outcomes, and impacts, a logic model helps stakeholders see the connection between planned work and intended results. Table 4.2.4 describes the stages of the logic model.

PROGRAM GOALS/OBJECTIVES AND THE LOGIC MODEL: Program *goals* and *objectives* form the foundation of a Logic Model to program design and evaluation, and they influence each component of the model. Goals and objectives provide overall direction and assist to define what success looks like at each stage of the Logic Model. Poorly articulated goals and objectives will therefore lead to ambiguity in program design, misalignment between activities and desired outcomes, and difficulties in measuring progress and impact. As noted previously, clear and well-defined goals and objectives are therefore essential to ensure that each stage of the Logic Model is purposeful, achievable, and effectively evaluated.

Figure 4.2.2 shows an example of this alignment and how the logic model can be applied to the hypothetical Darling Downs community engagement program. Program goals and objectives serve as the foundation for a Logic Model in program design and evaluation, influencing each stage of the model. They provide overall direction and define what success looks like at each stage of implementation. Vague or poorly defined goals and objectives can lead to ambiguity in program design, misalignment between activities and intended outcomes, and difficulties in assessing progress and impact. As previously discussed, establishing well-defined and clearly articulated goals and objectives is crucial to ensuring that each stage of the Logic Model is meaningful, achievable, and effectively evaluated.

Adopting the structured approach shown in Fig 4.2.2, particularly for those with limited experience in program design, helps create a logical connection between program resources, activities, expected outputs, and intended outcomes, ultimately improving the program's effectiveness and its ability to be evaluated.

Table 4.2.4 Characteristics of the Logic Model approach to program design

Stages of the Logic Model	Brief Description	Examples
Inputs (Resources)	These are the resources necessary to implement the program	• Funding (grants, sponsorships) • Human resources (staff, volunteers, experts) • Physical resources (equipment, facilities, technology) • Partnerships (schools, industry, universities, community organisations)
Activities (Program Interventions)	These are the key actions taken, and activities delivered, to implement the program	• Workshops, training sessions, mentorship programs • Curriculum development, STEM workshops/ challenges • Community outreach, industry site visits
Outputs (Deliverables and participation metrics)	Outputs are the tangible, early (and easily) measurable products of program activities	• Number of events or workshops held • Number of students, educators, or community members engaged • Number of resources distributed (e.g., toolkits, educational materials)
Outcomes (Short- and Mid-Term Changes)	These are the immediate and intermediate *effects* of the program	• Increased STEM awareness, confidence, or interest (short-term) • Growth in STEM skills, problem-solving ability, and career aspirations (mid-term)
Impact (Long-Term Change)	This refers to the broader, systemic changes resulting from the program	• Increased STEM career participation or university enrolments • Growth in industry-relevant skills within the workforce • Strengthened community engagement in STEM

Figure 4.2.2 Logic Model approach for region-wide Darling Downs Community STEM engagement program

Overarching Goal: *Engage and inspire regional and remote Darling Downs communities in STEM to enhance senior school studies in maths and science*

Objective 1: Increase STEM Participation – *Deliver interactive science workshops and demonstrations to 80% of schools in the Darling Downs region over the next three years, focussing on Year 7-9 students to encourage continued STEM education*

Inputs
(resources, funding)

- Funding (govt. grant, industry partner, university, CSIRO, Dept of Ed)
- People (STEM educators, parents, volunteers, industry mentors)
- Equipment (science kits, lab reagents, digital resources for online engagement
- Partnerships (schools, Universities, local councils (resources, funding)

Activities
(program implementation)

- Mobile STEM Lab, science shows, real world hands-on experiential activities etc.
- STEM career talks, parental engagement activities, Industry mentors
- STEM school challenges (e.g. STEM Cup, Science And Engineering Challenge
- Virtual STEM engagement (e.g. online workshops, virtual “scientists in the Classroom”)

Outputs
(immediate deliverables)

- 50+ workshops delivered Pre- and post –curriculum resources disseminated
- 80% of schools in Darling Downs participated in at least one workshop
- 5,000+ students engaged in hands-on STEM
- 200+ teachers participated in professional development STEM training
- 10+ industry partnerships established to support STEM outreach

Outcomes
(short-mid term effects)

- 70% of students report increased confidence in science and maths
- 60% of students express greater interest in senior STEM electives
- 80% of teachers report improved engagement in STEM lessons.
- 50% increase in enrolments for senior STEM subjects.
- 30% increase in student participation in STEM-related extracurricular activities

Impact
(long-term systemic change)

- Increased university enrolments In STEM courses from Darling Downs students
- More students from Darling Downs pursuing careers in STEM industries
- Strengthened regional workforce with local STEM employers hiring More graduates from the region
- Long-term partnerships between schools, universities, and industry stakeholders supporting ongoing STEM outreach

4.3 Capabilities and Capacity

This principle recognises that successful science engagement programs require appropriate capabilities (skills, expertise and knowledge) and capacity (resources, infrastructure and personnel).

4.3.1 Why, and in what ways, are capabilities and capacity important

Program capabilities and capacity can be considered the inputs into the Logic Model designs discussed above, where it was noted that shortfalls in any of these areas may result in programs struggling to achieve their objectives and intended outcomes. The following discussion highlights some the most important factors that influence the effectiveness, reach, and sustainability of community science engagement programs.

CAPABILITIES: Capabilities refer to the overall skill set of the team organising and delivering the engagement program. For example, having relevant STEM discipline experts, having engaged and culturally sensitive presenters, and having appropriate systems and processes for managing participant registrations. Key capabilities for community science engagement programs include:

Effective communication skills: Community engagement in science often relies on the ability to translate complex scientific ideas into accessible language and experiences for diverse audiences. The importance of engaging relatable scientists (or STEM professionals) is presented in detail later (in Chapter 5.3) where a strong emphasis on communicating clearly, using language free from technical jargon, is articulated (Fischhoff, 2013), and where explanations are readily adapted to various age groups, cultural backgrounds, and levels of prior knowledge (Dawson, 2014).

Audience engagement and facilitation skills: Effective audience engagement requires more than subject matter expertise and the ability to communicate it; it also requires strong facilitation skills. Successful facilitators promote interest and curiosity in science through hands-on, inquiry-based, experiential learning, encouraging participants to ask questions and explore scientific ideas actively (see (Bell et al., 2009) and see later, in Chapters 5.1. and 5.2). They are also skilful in creating an inclusive environment where all participants feel welcome, safe and valued is essential for meaningful engagement (Archer et al., 2015). Without these skills, engagement efforts risk becoming passive, didactic one-way presentations that fail to inspire interest.

Pedagogical knowledge: Programs that aim to complement formal education by engaging participants in informal, out-of-class, experiences will require an understanding of educational theories and science pedagogy (Falk & Dierking, 2010). In this context, pedagogy refers to the theories, strategies, and practices that guide how best to teach science and facilitate participant learning. It encompasses instructional methods that promote inquiry-based learning, conceptual understanding, and critical thinking (Council, 2000). It also considers students' prior knowledge, cultural backgrounds, and experiences, aligning with frameworks like constructivism (Piaget, 1952) and science capital (Archer et al., 2015) to make learning relevant and accessible. These ideas are considered in detail in Chapters 5.1 and 5.2.

Cultural competency and inclusivity: To engage diverse audiences, including underrepresented groups, program facilitators must develop cultural competency and inclusivity skills. This involves understanding the social and cultural barriers that can limit STEM participation and working to address these challenges (Archer et al., 2015; Dawson, 2014). Programs should be adaptable to different backgrounds and learning needs, ensuring that content is accessible and inclusive. This may require co-designing initiatives with local communities rather than imposing a top-down approach, to create a sense of ownership and local relevance.

Technological and digital literacy: In an increasingly digital world, community science programs must effectively integrate technology and digital tools/resources to reach broader audiences. Facilitators and organisers need to be competent in using multimedia tools, virtual platforms, and social media to engage younger audiences and extend program reach (Bonney, Ballard, et al., 2009). Digital capabilities are also essential for engaging remote communities with limited technological resources, preventing already existing digital divides from getting worse (Jenkins & Nelson, 2005). Programs that fail to incorporate digital tools effectively risk becoming outdated or inaccessible to key audiences.

Program design and evaluation skills: Chapters 4.1 and 4.2 have already detailed the rationale and importance of effective program design and evaluation – and therefore the knowledge and skill sets required of program leaders. Without robust design and evaluation expertise, community science programs will struggle to refine or adapt their offerings, struggle to measure outcomes and impact, and therefore struggle to secure ongoing funding and support (Jensen & Buckley, 2014; Patton, 2008).

Collaboration and partnership development: Most community science programs rely on collaborations with schools, universities, industry partners, or community organisations. Building strong partnerships requires relationship-building skills to build trust and cooperation among stakeholders (Kanter, 1994). Effective engagement strategies must align different interests and priorities, ensuring that partnerships serve mutual goals. Project management skills and expertise is also required for coordinating collaborative initiatives and maintaining long-term partnerships. Without these capabilities, programs may struggle to leverage external support.

Funding, grant writing, and financial management: Securing and maintaining financial support is essential for the sustainability of community programs. Program leaders must have strong grant-writing and proposal development skills to attract funding from government agencies, industry sponsors, and philanthropic donors. Financial planning and budgeting expertise are equally important to ensure that resources are allocated efficiently and that programs remain viable in the long term (Falk & Dierking, 2010). Additionally, government and industry advocacy are important to demonstrate the societal value of science programs, facilitating ongoing investment and support (Jensen & Buckley, 2014). Programs lacking these capabilities risk instability and therefore risk long-term sustainability.

CAPACITY: Capacity relates to the resources required to deliver the engagement in the desired mode. An assessment of staffing/volunteers, finance, space and time to accommodate the planned engagement program based on expected numbers of participants. For example, engagement programs that are delivered entirely online would require different staffing levels and different physical space requirements compared to an in-person event. Key capacity considerations for community science engagement programs include:

Staffing capacity: Well-trained and adequately staffed teams are essential for delivering effective community science programs. Programs with insufficient personnel struggle to manage large-scale events, develop educational materials, and maintain engagement with communities. Ongoing professional development of staff is essential to ensure they remain up to date with scientific developments and best practices in science communication, pedagogy, and engagement strategies. Without sustained investment in staffing levels and staff development, programs risk becoming outdated, poorly organised and delivered, and unable to meet the evolving needs of their communities.

Infrastructure, facilities, and digital space – reach and accessibility: Physical and digital infrastructure are very important for community science programs. Science centres, museums, university laboratories, and access to mobile engagement programs facilitate access to high-quality programs and experiences. However, these resources are concentrated in specific geographical regions, and are limiting for rural and underserved populations. Careful planning, the flexible use of existing spaces and development of robust digital platforms can facilitate remote engagement and expand access.

Financial resources: Sustained funding is required for staff salaries, equipment, transportation, and materials. Programs that rely solely on short-term grants often face challenges in maintaining continuity and impact –long-term investment from governments, private organisations, and philanthropic donors' results in increased stability and quality of program delivery.

Time: Appropriate time needs to be allocated for the design, delivery and evaluation phases. Time is needed to engage with communities to determine their needs, assess local resources, and build relationships. Time may be required simply to travel from the home institution/organisation to a regional or rural community, or frequent visits to build relationships with community leaders (Indigenous communities, immigrant, religious groups, local government, businesses, schools, etc). Time should also be allocated to completing evaluations and appropriate reports (formal and informal) delivered to interested stakeholders, including the communities.

4.3.2 How to assess capabilities and capacity

Assessing the capabilities and capacity of a team or organisation to design, deliver and evaluate a community science engagement program can be readily achieved using an audit approach. For team capabilities, a skills audit using a skills matrix provides a clear and simple way to assess capabilities required, capabilities currently available and capability shortfalls.

For organisational capacity, a resource audit can identify the necessary infrastructure, materials, and other essential resources, helping to highlight deficiencies to ensure adequate support for delivery of the activity/event/program.

CAPABILITIES – SKILLS MATRIX: A skills matrix is a visual tool used to map, assess, and manage the skills required for a team or project. It provides a visual representation of:

1. Required capabilities – the knowledge and skills (expertise) needed to complete a project or perform a role effectively.
2. Available capabilities – the expertise already existing within a team.
3. Capability gaps – areas of expertise where additional training, hiring, or resource allocation is needed.

By identifying strengths and weaknesses, a skills matrix helps program leaders optimise team performance, allocate tasks effectively, plan for staff training, and initiate a recruitment process if required.

Creating a skills matrix for community science engagement programs: Figure 4.3.1 shows an example of a possible skills matrix for science engagement programs. The left-hand column lists capabilities required for a particular activity/event/program. The remaining columns represents team member rankings, (1-4) for proficiency or skill in a particular required capability, and a score of (0 or 1) for that team member's interest in carrying out duties associated with that capability.

A skill matrix can be used in a semi-quantitative manner that allows program leaders to identify skills gaps among the team (as a whole) or for individuals. For example, if the activity/event/program referred to in Figure 4.3.1 required extensive social media engagement (with total ranking points = 3), the program leader might look at upskilling team members or recruiting an individual with social media skills.

A skills matrix is a simple, semi-quantitative, visual tool that can be valuable for assessing and managing the capabilities required to deliver community science engagement programs. By regularly updating skills matrices, community science engagement programs can ensure they are well-equipped and adaptable into the future.

Capacity – Resource Audit: A resource audit is a structured tool used to assess and manage the tangible and intangible resources required for, or available to, a community science engagement program or event. It provides an overview of:

1. Tangible resources required and available to support program delivery, including:
   - Physical resources such as buildings, labs, lab consumables, safety equipment, event spaces, IT infrastructure, AV equipment, transportation, and educational materials (brochures, worksheets, activity kits etc.)
   - Financial resources such as operational budget, government grants, private-sector funding, sponsorships, fee-for-service revenue, and in-kind contributions such as free venue use or donated materials
   - Human resources such as full-time and part-time staff, scientists, educators, volunteers, event coordinators, technical support personnel, communications and marketing specialists, community liaisons, emergency/first aid providers, security and crowd management teams.

2. Intangible resources, including:
   - Know-how resources, such as institutional knowledge, understanding of best practice engagement strategies, understanding of audience needs, and experience in designing delivering and evaluation programs
   - Reputational resources such as established partnerships with educational institutions, government agencies, and corporate sponsors; trust and credibility within the community; a successful track record of previous events or programs; social media presence and public perception.

3. Resource gaps, including where additional investments, partnerships, or reallocation of resources are required to deliver or expand activities.

By evaluating available and required resources, a resource audit helps program leaders address deficiencies and optimise resource allocation.

Figure 4.3.1 Example of a Skills Matrix for community science engagement programs

Capabilities	Team Member 1		Team Member 2		Team Member 3		Total
	Proficiency	Interest	Proficiency	Interest	Proficiency	Interest	
Program design and evaluation	2	1	3	1	1	1	**9**
Scientific knowledge	4	1	3	1	2	1	**12**
STEM Education and pedagogy	4	0	1	0	1	0	**6**
Communication and audience engagement	3	1	2	1	1	0	**8**
Digital engagement and social media	1	0	1	0	1	0	**3**
Event planning and logistics	2	1	2	0	2	1	**8**
Grant writing and fundraising	1	0	2	0	2	0	**5**
Sub-total	**17**	**4**	**14**	**3**	**10**	**3**	
Total	**21**		**17**		**13**		

Key	
Key	**Proficiency:** 1 = beginner; 2 = Intermediate; 3 = Advanced; 4 = Expert
	Interest: 0 = no interest in applying this capability; 1 = Is interested in applying this capability

Using a Resource Audit: Figure 4.3.2 shows an example of a possible resource audit for science engagement programs. The two left-hand columns list the broad resource categories and specific resources required for the event/program. The remaining three columns provide a structured assessment of each resource, namely:

- Availability (Yes/No) – determines whether the necessary resources are currently available or need to be acquired

- Adequacy (Sufficient/Insufficient) – evaluates whether the available resources are sufficient to meet program needs or require supplementation
    - this field could be given a score or ranking (e.g. 1-5) to provide a quantitative measure of adequacy
- Notes/Actions Required – identifies specific steps to address gaps, such as securing additional funding, recruiting personnel, acquiring new materials, or strengthening partnerships.

Figure 4.3.2 Example of a Resource Audit for community science engagement programs

Resource Category	Resource Type	Availability (Yes/No)	Adequacy (Sufficient/ Insufficient)	Notes/Actions Required
Physical Resources	Facilities and Venue Equipment and Supplies Digital Infrastructure			
Financial Resources	Funding and Grants Sponsorships Budget Allocation			
Human Resources	Staff and Experts Volunteers External Partners First aid officer			
Know-How Resources	Institutional Knowledge Training and Development			
Reputational Resources	Community Trust Stakeholder Partnerships			

A resource audit can be used qualitatively or in a semi-quantitative manner to assess strengths, weaknesses, and gaps across resource categories. Where existing capacity falls short of what is required, either additional resources are required, or the program is modified (e.g., alternate space used, activities modified, reduced number of participants, etc) to keep it within the available resources and budget. For example, if a community science engagement program relies on extensive digital outreach but lacks adequate digital infrastructure, leaders may need to invest in new technology or seek external partnerships. Similarly, if a program has strong funding but limited expertise in science expertise, efforts may be needed to train staff or recruit specialists.

By regularly updating resource audits, scientific engagement programs can ensure they have the necessary support, adaptability, and sustainability to achieve their objectives and deliver meaningful community impact.

A Final Word on Capabilities and Capacity – the Relationship to Program Goals and Objectives: Collectively, an organisation's capabilities and resource capacity constitute the *inputs* to the Logic Model approach outlined in Chapter 3.2. These inputs determine the scope of possible activities to be carried out, which must be strategically aligned with the intended outputs, outcomes, and impacts. When resources or expertise are insufficient or compromised, planned activities may need to be adjusted. In such cases, it is essential to reassess project goals, objectives, and expected outcomes to maintain alignment. Failure to do so may result in discrepancies between intended impacts and actual program execution, ultimately affecting the validity and effectiveness of program evaluations.

ADDITIONAL RESOURCES: The tables shown above are simple examples of a Skills Matrix and a Resource Audit. There is a myriad of other examples (including templates) readily available online that can be adapted to suit most needs in assessing capability and capacity requirements of community science programs. Examples are included in **Appendix C**.

4.4 Sustainability and Scalability

This design principle recognises that successful science community engagement programs should generally be designed for long-term viability while also having the capacity to expand and adapt to engage broader audiences across diverse geographical areas.

4.4.1 The importance of sustainability and scalability

When designing community science programs, careful consideration of sustainability and scalability is required to ensure long-term impact and increased reach and accessibility.

SUSTAINABILITY: Sustainability refers to a program's ability to continue delivering impact over time. For science engagement programs, this is typically achieved by securing long-term resources, institutional support, community involvement (including co-design and co-delivery), and ensuring ongoing program alignment to societal needs and government policies. Miguel et al. (San Miguel et al., 2019) characterises sustainable programs as those delivered within a *"framework of institutional, government, and community support, bolstered by mutual interests, with freedom for innovation and delivery outside of a formal classroom experience"*.

Sustainable programs can withstand funding challenges, staff turnover, and changes in government and societal priorities, ensuring that scientific engagement efforts remain relevant and accessible. By contrast, low performing programs are those that:

- are dependent on support and delivery by individuals or champions, volunteering their time in addition to their regular job responsibilities
- are highly dependent on external funding, and
- have limited reach due to limited resources (Eilam et al., 2016).

These programs and relationships tend to end when funding ceases or people spearheading the initiative leave (Greany et al., 2014).

SCALABILITY: Scalability refers to the capacity of a program to grow and adapt to increasing numbers of participants or to be replicated in different contexts, without compromising quality (Koch & Penuel, 2010) (Zamboni et al., 2019). This is sometimes referred to as 'scaling-out' (Van Lunenburg et al., 2020). Programs that scale-out can increase their reach to diverse populations, geographic regions, and socio-economic groups, ensuring that engagement opportunities are widely available. This is particularly important for science engagement programs, as a key goal is to reach diverse populations, generating broad interest in science with a view to diversifying the STEM pipeline. It is also particularly important in the Queensland and Australian contexts where there are large numbers of regional cities, rural towns and remote communities spread over vast distances.

Scalability also refers to having influence beyond the immediate impacts of science engagement, for example, influence on organisational priorities, public discourse or political agendas. This is sometimes referred to as 'scaling-up' (Van Lunenburg et al., 2020) and involves embedding science engagement into, for example, institutional policies, educational practice and government strategies. By affecting institutions and organisations in this way, scaling-up can position science engagement programs as a valued civic enterprise contributing to lasting systemic change.

SUSTAINABILITY VS SCALABILITY: Sustainability and scalability are closely related, as scalable programs generally have a requirement to be sustainable, and sustainable programs often require scalable models to maximise reach, financial efficiencies, and influence. Programs that are scalable but not sustainable may expand rapidly but collapse due to a lack of resources or long-term commitment; while programs that are sustainable but not scalable may have long-term viability but remain limited in scope and fail to achieve widespread impact (Eilam et al., 2016).

Sustainability is not just about keeping programs running – it is about remaining impactful, inclusive, and relevant over time; and this can only happen when programs grow, evolve and scale. And scalability is not just about program accessibility, inclusivity and reach ('scaling out') – it is also about 'scaling up' to influence and impact organisational priorities, public discourse and government policy.

Effective community science engagement programs must balance both parameters to ensure broad, long-lasting community impact.

ADVANTAGES OF SUSTAINABLE AND SCALABLE PROGRAMS: Designing and delivering sustainable and scalable programs offers far-reaching benefits beyond merely expanding participation numbers over time and distance. These programs also enhance accessibility and inclusivity, promote greater scientific literacy and science capital, strengthen institutional and community support, and ensure long-term financial viability.

Greater reach and accessibility: One of the primary benefits of sustainable and scalable science engagement programs is their ability to reach diverse populations without compromising quality, including the potential for increased engagement among underrepresented groups in regional, rural and remote areas. Unfortunately, many science engagement programs often fail to engage underrepresented communities due to complex logistics and resource limitations. However, programs that integrate sustainability and scalability considerations during their initial phases are more likely to succeed in the long run (Friesner et al., 2021; Koch & Penuel, 2010; Zamboni et al., 2019). These programs can expand effectively compared to programs that lack such planning, which often remain limited in scope and fail to engage broader audiences beyond their initial target groups.

The link between long-term engagement and science capital: Ongoing, sustainable programs offer participants multiple opportunities for engagement rather than one-off participation. This presents significant advantages in increasing the 'science capital' of participants. For example, multiple interactions, that are well planned, will lead to:

- Increased understanding of scientific concepts and processes (i.e. *what you know*), through, for example, opportunities for active, hands-on, experiential learning opportunities
- Improved attitudes and aspirations (i.e., *how you think*) through, for example, applying science and scientific methods to real world contexts that have personal relevance; leading to a sense of "belonging in science" and developing the notion that science is "for me"
- Increased opportunities for ongoing engagement with science related activities and events (i.e., *what you do*) through, for example, attending afterschool science clubs, science centres, museums, maker spaces etc.
- Increased opportunities for expanding scientific networks (i.e., *who you know*) through, for example, engaging directly with scientists, STEM professionals, and STEM role models – particularly those with personal relevance (e.g. women in STEM, Indigenous scientists and professionals from a variety backgrounds) to help dismantle stereotypes.

Organisational know-how: A key advantage of sustainable science programs is the accumulation and retention of organisational 'know-how'. This includes the collective knowledge, expertise, and institutional memory that ensures impactful program planning, delivery, and evaluation – for example best practice procedures, operational policies, training manuals, evaluations frameworks etc. Moreover, organisations with institutionalised knowledge and established processes can more easily adapt to new challenges and can more readily scale their initiatives to different audiences and/or different regions.

Institutional support: Sustainable, large-scale programs tend to readily integrate into existing organisational structures, allowing them to benefit from long-term institutional support. Research by Sadler et al. (K Sadler et al., 2018) note that university-based STEM outreach programs often struggle due to inadequate institutional support, particularly smaller or individually led initiatives. In contrast, larger, longer-term programs are more likely to receive support from key institutional departments, such as university marketing teams, enhancing their visibility and sustainability. Freisner et al. (Friesner et al., 2021) also note that *"institutional support is key to success"* in university settings.

Institutional backing is especially crucial given that science engagement initiatives embedded within universities, government agencies, and non-profit organisations tend to have greater longevity and broader reach compared to independent, short-term efforts. Programs that incorporate sustainability and scalability into their design significantly increase their chances of seamless integration into organisational structures, thereby reaping the benefits of ongoing institutional support.

Community support: A key factor in successfully scaling or adapting programs to new contexts and regions is actively involving local communities in co-design and implementation. Programs that engage local communities in leadership roles create a sense of ownership among participants, making them more likely to advocate for continued support and funding (Evans-Agnew & Eberhardt, 2019). This community-driven sustainability model ensures that engagement does not depend solely on external funding but is maintained by local stakeholders.

Financial viability: Larger sustainable community programs tend to have diversified revenue streams, securing funding from multiple sources thereby mitigating financial issues associated with relying on a single stream of monetary input (Akins, 2015). Moreover, organisations with a proven long-term impact, and those that re-invest in building capacity and capabilities (e.g. staff training), enhance funding opportunities since funders favour: i) well-managed organisations; and ii) programs that demonstrate a higher return on investment in terms of societal benefits (Akins, 2015).

Consequences of Ignoring Sustainability and Scalability: Programs that fail to consider sustainability and scalability often experience negative consequences, including:

- Short-lived impact – programs that are not sustainable may cease to operate after initial funding ends, limiting long-term benefits and resulting in lost resources and knowledge
- Limited reach – programs not designed for scalability often fail to expand beyond their pilot phase, limiting wider impact
- Community disengagement – without long-term sustainability planning, and continual refinement and refreshment of program structure and activities, community participants may lose interest
- Missed policy influence – programs that lack scale fail to generate widespread impact, reducing their ability to influence organisational change and government agendas.

4.4.2 How can programs be designed (or adapted) to be sustainable and scalable

Program sustainability and scalability require long-term planning, adaptability, institutional support, effective leadership, and strategic partnerships to ensure continued impact. Lunenburg et al. (Van Lunenburg et al., 2020) highlight that institutional environments, personal characteristics of program leaders, and overall strategic approach (goals, objectives etc) are crucial for ensuring long-term scalability – *"Programs that integrate collaborative structures, strong leadership, entrepreneurial skills, and institutional support tend to scale more effectively";* while Lambin et al. focus on sector alignment where effective *collaboration* is the key to scalability and requires "*collaborations across public, private, and civil sectors to align motivations and maintain a balance of incentives*" (Lambin et al., 2020).

Koch et al. (Koch & Penuel, 2010) expand on this notion by articulating five key strategies for scaling STEM engagement programs – the first four of which relate to local collaborations:

- co-designing with stakeholders
- achieving spread (i.e., scale) through partnerships
- developing local ownership from the beginning rather than transferring ownership later
- sustaining programs through professional development, and
- creating adaptable program structures.

The ideas above are captured in the following key best practices for designing and implementing community science programs that are both sustainable and scalable – starting with the final point relating to program structures and design.

Embed Sustainability and Scalability into Initial Program Design: There is strong support in the literature for integrating sustainability, scalability, and transferability into the initial program design and evaluation stages of community engagement programs (Friesner et al., 2021; Koch & Penuel, 2010; Zamboni et al., 2019). As Koch and Penuel (2010) note, *"rather than leaving thinking about sustainability and dissemination plans until after a program design has been articulated, scale and sustainability plans should be integral to the conception of the innovation"*(Koch & Penuel, 2010). An effective approach that program designers could consider is provided by Friesner et al. (Friesner et al., 2021), who modify a Logic Model approach to program design by embedding sustainability and scalability goals from the outset. This approach ensures that these objectives inform and shape all elements of the model (inputs, outputs, outcomes and impact), so that long-term viability and broader applicability are at the forefront of program development. Similarly, Edwards et al. (Edwards et al., 2021) develop a Logic Model approach for a large, national-scale outreach program targeting underrepresented youth.

However, it may be prudent to proceed with caution for newly developing programs. A recent review of scale-up frameworks by Zamboni et al. (Zamboni et al., 2019) highlights a fundamental tension between the need to establish proof-of-principle for fledgling programs and the aspiration to design a program that is inherently scalable from inception. This may require program designers to balance an initial focus on demonstrating proof-of-concept in a specific context against a broader desire of ensuring the program can be adapted and expanded. Designing for scalability too early may introduce complexities that hinder initial success, while delaying scalability considerations can make later expansion more challenging.

Notwithstanding this note of caution, it is strongly recommended that, as soon as practically possible, sustainability and scalability be embedded as core program characteristics within the overall strategy. This should be reflected in goal and objective statements in the program's design and in its implementation.

Keep Structures and Practices Simple: Programs with clear, straightforward, goals and objectives, and whose operational structures and practices require limited resources and funding, have a greater likelihood of being sustained and scaled (Clark et al., 2016; Ramirez, 2011; San Miguel et al., 2019).

This is especially true when structures and activities are designed with flexibility and adaptability in mind, incorporating easily replicated modular activities with clear operational documentation. Such features readily enable transfer to different contexts and regions with limited compromising of quality or efficiency.

The integration of technology can also significantly enhance scalability. Digital approaches (such as mobile apps, virtual communication sessions, and data collection platforms) can facilitate knowledge transfer, and reduce logistical barriers, while being easily transferred to new contexts and locations.

Community Buy-in and Ownership: "*To achieve durable impacts, the upscaling of solutions to reach sustainability must continually maintain a balance of incentives among key actors … there is no quick fix: stakeholders must build solutions together*" (Lambin et al., 2020). Long-term sustainability and scalability of science engagement programs generally rely on development of strategic partnerships and securing strong buy-in from key community stakeholders.

Co-design and community ownership: Community-led initiatives tend to be more sustainable and impactful. Inclusion of local communities in the design and delivery of programs will enhance community uptake and promote a sense of ownership (Evans-Agnew & Eberhardt, 2019; Fisher et al., 2019). By implementing co-design frameworks, forming advisory groups with local leaders, training of local facilitators and developing community-led governance structures, programs can ensure ongoing community engagement and support even when central, or external, support diminishes (Evans-Agnew & Eberhardt, 2019).

Fisher et al. (Fisher et al., 2019), highlight that place-based educational studies and place-based community engagement initiatives are inherently scalable. These approaches use local settings as a framework for student learning, and broader community engagement. They focus on specific geographic locations, communities, or environmental contexts to explore real-world issues of local relevance – and they typically involve locals as 'experts' in program delivery. By careful, deliberate, designing of programs that can be adapted to (and be meaningful for) specific communities, program leaders can ensure that science engagement efforts resonate with diverse audiences across Australia.

Citizen Science initiatives offer another valuable approach to enhancing both the scalability and sustainability of programs. These initiatives actively engage community members in data collection (and sometimes data analysis), empowering participants to address local issues through scientific inquiry (Abourashed et al., 2021; McKinley et al., 2024). While they help bridge the gap between academic research and local knowledge, their true significance lies in promoting inclusivity (aligning scientific efforts to locally relevant contexts), and in affecting community values and attitudes toward science (Agnew et al., 2022; Bonney et al., 2014; Dickinson et al., 2012). This dual impact enhances the long-term viability of citizen science initiatives. Moreover, the nature of citizen science programs facilities scalability because locally driven data collection efforts are readily replicated in diverse locations while still preserving scientific rigour and local relevance.

Building local capacity and capabilities: Chapter 4.3 highlighted the importance of programs investing in human capital to ensure long-term sustainability. The same is true for expansion of programs into other regions. Koch et al. (Koch & Penuel, 2010) highlight the importance of creating a local professional development infrastructure for upscaling, while Evans-Agnew et al. (Evans-Agnew & Eberhardt, 2019) stress that community-led capacity-building initiatives strengthen program ownership.

A particularly successful Australian program that has achieved this is the University of Newcastle-led *Science and Engineering Challenge* (SEC) (Reed et al., 2021). By partnering with local organisations, most notably Rotary Australia, the SEC has empowered communities to take ownership of the program's delivery through training local facilitators, and volunteers, as well as providing ongoing mentorship and leadership development. Investing in local capacity-building and establishing strong community partnerships, has created a sustainable and scalable model that not only inspires students but also empowers communities to take an active role in STEM education, engaging an impressively large number of communities across Australia.

In many ways, this approach is summed up by Clark et al. "*The simple structure and distributed responsibility of this program allows for scalability and continuity"* (Clark et al., 2016).

STRATEGIC PARTNERSHIPS AND DIVERSIFIED INCOME STREAMS: Van Lunenburg et al. (Van Lunenburg et al., 2020) emphasise the role of multi-sector coalitions in driving program upscaling, while Zamboni et al. (Zamboni et al., 2019) highlight the importance of diversified and collaborative funding models in sustaining long-term impact. Programs that establish cross-sector collaborations and explore varied funding mechanisms are better positioned to adapt and expand over the long term.

Leveraging strategic partnerships for growth: Community science programs leaders should be encouraged to form strategic alliances with a range of potential collaborators including educational institutions, research institutions, government agencies, private sector entities, and community-based organisations. These partnerships will strengthen community science programs by combining expertise, resources and infrastructure from diverse stakeholders. They also provide credibility, regulatory support, and financial investment, all of which are crucial for long-term sustainability and scalability.

"Collaborations and Partnerships" are addressed in more detail in Chapter 4.5, where practical advice for establishing and maintaining these types of alliances is provided.

Ensuring financial sustainability through diversified income streams: Long-term program sustainability requires financial stability, which is best achieved through a diversified funding model. Relying on a single funding source creates risk and limits the ability to expand. To mitigate this, programs should incorporate a mix of public funding, private sector investment, self-funded income streams, and community-driven financial support.

Government funding (at three levels of government) remains the key source of financial stability for community engagement programs, particularly through community grant schemes, educational funding schemes, and policy-backed initiatives. Therefore, aligning program goals and objectives with government priorities will increase access to funding opportunities while also reinforcing the program's rationale and strategic value.

However, programs should also be complemented by seeking corporate sponsorships and philanthropic investments, which provide flexible financial support. Many private companies are willing to invest in STEM education and community engagement programs through their internal corporate social responsibility (CSR) initiatives This can come in the form of direct funding and/or in-kind support such as professional expertise or access to technology or infrastructure.

Beyond external funding, programs can explore self-sustaining revenue models including:

- fee-for-service models, where participating individuals or organisations contribute to program costs
- a membership-based model, through for example, annual subscriptions – similar to models employed in museums and science centres, and

- online crowdfunding or grassroots community fundraising activities, allowing individuals and local businesses to contribute directly to fledgling programs or ongoing sustainability of existing programs.

Another viable approach is the commercialisation of program assets, such as licensing of program expertise and resources – for example, curriculum materials, educational kits, or provision of professional development courses.

Organisational Structure and Individual Leadership: The literature shows that actor characteristics, such as the ambition to scale, have a significant impact on program sustainability and growth – whether that actor is an organisation or an individual.

The organisational structure of community programs influences their flexibility and therefore impacts the propensity for scale and longevity. An extensive review of 133 social impact organisations by Van Lunenburg et al. (Van Lunenburg et al., 2020), has shown that open governance structures, in which there is room to experiment with different approaches and strategies, helps programs to scale.

Open structures prioritise adaptability and decentralised decision-making, making them well-suited for grassroots, community-led, volunteer-driven initiatives. They are characterised by broad participation and rapid innovation but often lack standardised procedures and formalised guidelines, which can lead to uncertainty in decision making and long-term stability.

By contrast, formal structures are characterised by overt governance frameworks and formalised operational procedures and guidelines, including long-term planning mechanisms. Expansion efforts are therefore carefully considered and carefully structured. Such rigid requirements may discourage some grassroots contributors from engaging fully and therefore limit community driven adaptations.

For many community science programs, the most effective approach may involve combining elements of both structures, for example, having local, decentralised (or distributed) delivery of programs with centralised support. This will allow co-design of program with core (consistent) program principles while allowing for location-specific modifications.

The literature also identifies personal characteristics of the program leadership as important, with "ambition to scale" being a particular predictor of impact (Van Lunenburg et al., 2020). Additionally, leadership capabilities, entrepreneurial skills and a balanced approach that places equal focus on economic considerations and social impact are considered important.

Ongoing Assessment and Adaptability: Sustainable and scalable programs must be responsive to emerging trends, such as those in the education sector, and adapt to evolving community needs, both locally and more broadly. Chapter 4.2 explored the importance of continuous formative evaluation in science engagement programs, not only for monitoring outputs, outcomes, and impacts but also for guiding program development. Effective evaluation approaches improve program evolution ensuring that stakeholder feedback informs continuous improvement, relevance, and adaptability. This iterative approach ultimately contributes to program sustainability and scalability.

"Durable STEM Education Programs – Evidence from Diverse Fields" (CSIRO, 2024): A recent CSIRO study (CSIRO, 2024) reviewed community engagement programs in environmental, health, education and social sciences fields to identify factors contributing to durability, sustainability, and effectiveness of STEM education programs. In this context 'durability' refers to *"The measure of how long-lasting the impact of a program or project is over time and its ability to withstand counteracting forces"*.

The review identified 248 factors, grouped into 10 categories under three overarching themes relevant to the durability of STEM education programs. Table 4.4.1 provides a set of practical recommendations across the three overarching themes. These recommendations strongly reflect the best-practice principles discussed in the preceding sections.

Program leaders and designers are encouraged to use the recommendations in Table 4.4.1 as a planning and reflection tool – or as a checklist to inform program design for long term impact.

4.4.3 Case study: the *Science and Engineering Challenge*

The University of Newcastle's Science and Engineering Challenge is a nationwide STEM outreach program that seeks to engage and excite Year 9 and 10 students about pursuing STEM studies into Years 11 and 12 and beyond. By working with Rotary and Australian universities, the program has operated for more than 25 years, engaging and exciting a diverse range of students including rural, Indigenous and female students. Students travel to one of the 30 or so universities that assist to host this national program and complete a range of hands-on activities to solve different challenges. Since 2000, more than 500,000 students have participated in the program.

Over a nine-year period (2006-15) more than 5,000 high school and ~2,400 first-year university students were surveyed to determine if participation in the program had influenced their decision to pursue further science studies in high school or at university (Reed et al., 2021). The greatest impact was observed for high school physics students, where ~52% reported that the program had influenced their decision to study physics. A smaller but still significant number of students pursued studies in Chemistry (~35%) and mathematics (32%) after participating in the Science and Engineering Challenge. Interestingly these positive effects were observed years later, with ~31% of first year STEM university students acknowledging the program had influenced their decision to pursue a STEM degree and career (Reed et al., 2021).

For additional resources on Sustainability and Scalability, see **Appendix D**.

Table 4.4.1 Recommendations for increasing the durability of STEM education programs (reproduced from (CSIRO, 2024))

Program dynamics	Community and resource dimensions	Strategic foundations
Durable STEM education programs:		
Are designed with a clear vision and long-term goals, and with durability and scalability in mind (specifically an explicit strategy for achieving sustained impact) Are designed with diverse voices and perspectives, which ensures that the program is tailored to the specific needs and challenges of the community it serves, ultimately leading to a more durable program. Have long-term planning, monitoring and evaluation processes in place, including incorporating regular assessment and feedback mechanisms to track progress and make data-driven decisions, and having contingencies for post-program monitoring and evaluation. Are based on robust education, social, and personal theory and research that underpins the design and implementation of the program. Have adaptability to changing conditions and needs built in the from the beginning, specifically, flexibility to respond to the evolving demands of the STEM industry and the changing interests of students. Have the ability to grow, either in terms of scaling to more locations, different participant groups, or having deeper impact.	Have partnerships within and across institutions, communities, and with external organisations. Building strong relationships with industry professionals, educational institutions, and community organisations can provide valuable resources and support for STEM programs. These partnerships can enhance the real-world relevance of the curriculum and offer students and teachers opportunities for mentorship and hands-on learning experiences. Have stakeholders and partners that are supportive of the program's vision and outcomes. Engaging stakeholders such as educators and community members in the program's development and execution can lead to a more invested and supportive community, which fosters a sense of ownership and shared responsibility. It also ensures that the program is tailored to the specific needs and challenges of the community it serves, ultimately leading to a more durable program. Maintain a stable financial environment with strategies for ongoing funding from diverse sources and exploration of avenues for new revenue streams	Have a vision, values and objectives that align with host organisation, community and industry workforce needs, curriculum, broader educational needs, and relevant policies and regulations Have strategic and effective leadership and program champions, including potentially distributed leadership within community networks and schools Ensure that the program has the necessary support from the hosting organisation that is backed by a committed team can have a positive impact on its durability Boost the capabilities and resources of all project participants to ensure they continue to apply program impacts into the future Identify and mitigate potential risks early in the project lifecycle

4.5 Strategic Alliances – Collaborations and Partnerships

This principle recognises the considerable value in establishing strategic alliances with range of partners for enhancing the effectiveness of community science engagement programs. Whether through co-design, financial support, knowledge-sharing, or logistical assistance, strong cross-sector community alliances (e.g. government, education, industry) enhance all aspects of program design, delivery and evaluation.

4.5.1 Why are collaborations and partnerships Important?

This document has already highlighted several approaches demonstrating the importance of collaborations and partnerships for amplifying the impact of community science engagement programs. These are briefly addressed here.

Enhanced knowledge and resource sharing: Leveraging expertise, resources, funding, and infrastructure from multiple organisations increases program capacity and capabilities. This enhances scientific and educative expertise, and access to scientific equipment and materials, as well as improving all aspects of program development, delivery and evaluation. It also reduces duplication of efforts from multiple organisations operating in the same field, optimising cost effectiveness of local programs – particularly considering the limited funding and resources available to community programs.

Increased community engagement and buy-in: Partnerships with local organisations, schools, and cultural groups create a sense of shared responsibility and community buy-in, ultimately building trust and enhancing program relevance. This is particularly crucial for ensuring continued engagement beyond proof-of-concept and initial funding cycles, preventing over-reliance on external/central leadership.

Stronger institutional support: Formal partnerships with universities, schools, and government agencies increase program credibility and provide a higher degree of legitimacy. They also provide a pathway long-term sustainability.

Diversified funding opportunities: Multi-sector collaborations open doors to government grants, industry sponsorships, and philanthropic investments, reducing reliance on a single funding source.

Scalability and adaptability: By leveraging established networks and local expertise, programs will have the know-how and resources to expand into new regions and adapt to different cultural and geographic contexts, while maintaining quality.

Additional Benefits (Not Already Addressed)

Reciprocal learning and workforce development opportunities: Collaborative partnerships create reciprocal learning opportunities for scientists, educators, and industry professionals allowing them to exchange expertise, support STEM career pathways, and guide community engagement initiatives to align with workforce needs. These partnerships can also bridge education and workforce development by offering career mentorships, internships, and real-world problem-solving experiences that align with industry needs. As a result, participants gain practical skills and knowledge about career pathways, while industries benefit from a well-prepared and diverse talent pipeline.

Enhancing diversity and inclusivity: Collaborations and partnerships can facilitate equitable opportunities for underrepresented groups by connecting community science programs with organisations and cultural groups having diverse perspectives and lived experiences.

By involving diverse role models and co-opting expertise, partnerships can ensure engagement efforts are inclusive, culturally relevant, and accessible – thereby positively affecting attitudes and aspirations, and helping participants see themselves in STEM fields (Bevan et al., 2018).

Diversity, inclusivity and accessibility are addressed in more detail in Chapter 4.6.

4.5.2 Implementing strategic alliances

Research on community science engagement programs typically describes the nature of engagement, the outcomes achieved, and the stakeholders involved. However, relatively few studies examine how to establish stakeholder alliances from the outset (Knippenberg et al., 2020). Nor do they consider the depth of stakeholder engagement—for example, whether it constitutes a partnership or a collaboration.

The following discussion will address these two issues, offering practical guidance and resources for effectively building and sustaining partnerships and collaborations in community science engagement programs.

COLLABORATIONS VS PARTNERSHIPS: When forming strategic alliances with individuals or organisations, it is important to consider the depth of these relationships, either at the initial stages of development or some time thereafter. For example, will the relationship be formal or informal? Will be it be short-term or long-term – or will these characteristics evolve over time? In other words, will the relationship be a partnership or a collaboration? While these terms are often used interchangeably there are differences in scope and level of commitment, and it is worth having a shared understanding (and common language) of each from the outset.

Partnerships tend to involve longer-term, more formal relationships between two or more entities that work together toward common goals and objectives. They often involve contractual agreements, sharing of resources (including finding), and have defined roles and responsibilities for individuals that are overtly articulated. They also tend to be a bigger picture, strategic**,** commitment to mutual benefit over time.

By contrast, collaborations are generally less formal, more flexible, and shorter-term relationships. They typically involve individuals working together on a specific project, event, or objective. Collaborations are often opportunistic, forming when mutual interests align, and tend not to involve shared financial or legal commitments. The key differences are summarised in Table 4.5.1.

Table 4.5.1 Comparing and Contrasting Partnership and Collaborations

Feature	Partnerships	Collaborations
Formality	Formal (agreements, contracts, MOUs)	Informal or flexible
Duration	Long-term	Short-term or project-based
Commitment Level	High (shared goals, responsibilities, risks)	Lower (mutual interest, no long-term obligations)
Resource Sharing	Often includes funding, personnel, infrastructure	Typically involves knowledge, time, or expertise
Structure	Well-defined roles, accountability	Loose structure, evolving roles

COLLABORATIVE ADVANTAGE: There are several well-established frameworks in the peer-reviewed literature that provide guidance for establishing and evaluating partnerships and collaborations for community engagement programs (Bryson et al., 2015; Kania & Kramer, 2011; Kanter, 1994). One approach that has gained significant traction over the last couple of decades is Kanter's notion of *Collaborative Advantage* (Kanter, 1994) where the true value in partnerships lies in synergistic collaboration (*creating new value together*), rather than mere exchange (*getting something back for what you put in*).

Kanter's partnership model is built on six key principles: excellence, importance, interdependency, co-investment, integration, and evolution. These principles are briefly outlined below in the context of formal partnerships, but they are equally applicable to less structured collaborative alliances.

Excellence: Partnerships should be driven by a shared commitment to high standards and excellent outcomes. Excellence in collaboration means that all parties bring their best expertise, capabilities, and resources to the table, striving for optimum results rather than settling for mediocrity. Excellence equates to credibility and leads to mutual trust, making partnerships more sustainable.

Importance: Successful partnerships are built on shared priorities and missions that matter deeply to all involved. Importance means that the collaboration aligns with the strategic goals of each partner and addresses a significant need or challenge. In community science engagement, this could mean working together to improve STEM literacy in underrepresented communities. When a partnership is perceived as essential, it is more likely to receive long-term support and investment (Bryson et al., 2015).

Interdependency: Mutual reliance between partners strengthens collaboration. Each party must bring something unique to the table, making the partnership more than just the sum of its parts. Interdependency ensures that no single entity dominates the collaboration and that all partners benefit from the relationship. In community science programs, this could take the form of exchanges of expertise, resources and staff – for example, secondments, placements etc). When interdependency is recognised and realised, partners are more likely to stay committed and actively contribute(Vangen & Huxham, 2005).

Co-Investment: Partnerships require shared commitment in terms of resources, effort, and responsibility. Co-investment involves both financial and non-financial contributions, such as personnel, time, and expertise, ensuring that all partners have a stake in the success of the initiative. This principle reinforces accountability and deepens engagement among stakeholders (Googins & Rochlin, 2000). In community science engagement, co-investment could involve a local business providing venue space, or a not-for-profit organisation contributing volunteers.

Integration: Integration is about embedding collaboration within the core structures and processes of all partner organisations. Rather than being a peripheral activity, the partnership becomes a fundamental part of how each organisation operates. Effective integration requires clear communication, shared decision-making, and aligned operational processes. Strong integration reduces friction and enhances the efficiency of the collaboration (Selsky & Parker, 2005).

Evolution: Successful partnerships must be dynamic and adaptable, evolving in response to changing needs, emerging opportunities, and lessons learned. Evolution ensures that collaborations remain relevant and continue to deliver value over time. In community science engagement, this might involve expanding programs to other regions and audiences or re-directing program focus in response to policy changes or community needs. Regular evaluation and reflection (Chapter 4.2) avoids stagnations and enables partnerships to grow (Van Tulder et al., 2016).

Establishing effective partnerships and collaborations is fundamental to the success of any science engagement program hoping to operate sustainability at scale. Integrating the elements of Kanter's model described above will significantly enhance the strength and sustainability of new partnerships. These principles can also be used as a benchmark to assess existing collaborations, to provide valuable insights into their effectiveness and identify areas for improvement.

Implementing Existing Partnership Frameworks: Bryson et al. (Bryson et al., 2015) extend on Kanter's collaborative advantage ideas by listing the following Practitioner Points to assist with practically creating and maintaining partnerships and collaborations:

- Make sure there is a clear collaborative advantage to be gained by collaborating, meaning that collaborators can gain something significant together that they could not achieve alone.
    - Make use of windows of opportunity to advance the collaboration approach.
- View collaborations as complex, dynamic, multilevel systems.
- Collaborating parties should take a design approach to cross-sector collaboration. This means starting as much as possible with the ends in mind and designing processes, structures, and their interactions in such a way that desired outcomes will be achieved and required accountabilities met.
    - Build ongoing learning into the design, including learning about what goals and performance indicators should be.
- Make sure that committed sponsors, champions, and facilitators are involved throughout.
- Use inclusive processes to develop inclusive structures, which, in turn, will sustain inclusive processes.
- Adopt flexible governance structures that can adjust to different requirements across the life cycle of the collaboration.

Provided below are some practical steps to *establishing* and *maintaining* partnerships, drawing on Kanter's Collaborative Advantage framework and Bryson's Cross-Sector Collaboration framework.

Establishing Partnerships

Identifying Potential Partners: Begin by mapping the STEM landscape in the local community. Identify stakeholders across sectors who share an interest in STEM engagement. For example, schools, outreach programs, museums, science centres, universities, local businesses, libraries, and not-for profit community groups. Consider less obvious allies too, such as parent associations, civic groups, sporting clubs or government agencies. Do your homework by researching existing STEM networks or initiatives; in many cases, you can join or piggyback on an existing partnership rather than starting from scratch.

Mapping the local STEM landscape saves time and helps to tap into already-established relationships. Approaching potential partners with knowledge of their mission and how a collaboration could benefit them will make your invitation more compelling (i.e., a win-win Collaborative Advantage scenario).

Aligning Goals and Expectations: Once potential partners are identified, take time to assess and align goals. Openly discuss each organisation's motivations and constraints to ensure the goals truly overlap. All parties should clearly understand and agree on the purpose of the partnership and have a shared understanding of the project's goals, objectives and expected outcomes.

Where appropriate, establish mutually defined roles and responsibilities early on – for example, who will lead certain activities? What resources will each partner contribute? Who will be responsible for reporting outcomes? Detailing these points in writing (e.g. via a memorandum of understanding, MOU) helps prevent confusion later.

Finally, give early consideration to expected long term impacts. Kanter's Collaborative Advantage framework posits that effective partnerships are not just transactional – they involve creating new value together and offering each partner *"an option on the future"* beyond immediate project gains. Partners should therefore develop a shared vision of long-term impact that aligns with each organisation's mission (e.g. increasing post-compulsory school studies in STEM or improving science literacy of junior secondary students in local schools).

Building Trust: Trust is the foundation of any strong collaboration and requires transparency and reliability. Share information openly, follow through on commitments, and respect what each partner brings to the alliance (expertise, resources, funding).

Spend time getting to know your partners' organisation and its people – it is not common interests and shared visions that bond organisations together; it is the relationships between individuals. Engaging in regular joint planning workshops or informal catch-ups can help partners create bond on a personal level. This will encourage an environment where ideas and feedback can be freely exchanged, signalling trust and a genuine collaborative mindset from the start.

According to Kanter, partnerships function as living systems that evolve over time, and they *"cannot be controlled by formal systems, but require a dense web of interpersonal connections."* (Kanter, 1994).

MAINTAINING AND STRENGTHENING PARTNERSHIPS: Establishing a partnership is only the beginning – active effort is needed to keep it healthy and productive over time.

Communication strategies: In Bryson's cross-sector collaboration framework, trust and ongoing communication are depicted as the lifeblood that keeps the partnership moving in the right direction. Schedule regular check-ins or coordination meetings (e.g. monthly calls or quarterly forums) where each partner updates on progress and challenges. This includes listening as much as sharing and acknowledging each partner's contributions and concerns. When issues or changes arise, discuss them openly and transparently rather than letting tensions simmer.

Adopting simple communication practices like having a single point of contact in each organisation and maintaining detailed meeting notes can go a long way. Publicly celebrating the successes of the collaboration can also ensure everyone feels valued and stays vested in the program.

Shared decision-making: Successful collaborations have governance structures that involve all partners in decision-making. Create joint decision-making processes such as establishing a steering committee with joint representation to guide strategy.

Agree on how decisions will be made (consensus? majority vote? designated leads?) so that everyone has a voice. Embrace the mindset that collaboration *"means taking away some control in order to create a greater benefit."* (Holderman, 2015). As Crosby and Bryson note (Crosby & Bryson, 2005), power and responsibility should be distributed in a *"*shared-power world*"* where no single entity is in charge.

Resource Allocation: Along with shared decision-making, be deliberate and equitable in resource allocation. Transparency in how funds, staff time, or materials are contributed and used builds confidence that the partnership is equitable. Partners can combine resources (funding, facilities, expertise) in ways that benefit all. Resource audits and a review of joint resource commitments should occur on a regular basis and adjustment made if one party is over-extended or if new resources become available.

Adapting and Evolving Partnerships: Community priorities and government policies change – partnerships will therefore need to adapt. As part of ongoing formative evaluations, programs need to stake stock of partnerships to consider what is working well, what challenges have emerged, and how community needs have evolved. Programs and partnerships should be willing (and able) to redefine objectives, roles, or activities as circumstances change.

Program changes may be positive in nature, for example the partnership's initial goal (say, a yearly science fair) has been met and now partners want to tackle a new goal (like a mentorship program). Or maybe funding cuts require scaling back in one area and ramping up in another. When this is required, use the jointly developed vison and goals to guide decision making. Understand from the start that partnerships and collaborations are evolving relationships – living systems that *evolve progressively in their possibilities* – that require constant attention.

WHERE TO START? – PRACTICAL RESOURCES: A curated selection of practical resources for both general and STEM-specific partnerships is provided in **Appendix E**, including Australian and international examples.

4.5.3 Case Study: *'Suzie the Scientist'* and '*Millie the Mathematician'*

Griffith University's *Science on the GO!* outreach program partnered with Rotary District 9640 and P&Cs Qld to co-develop *Suzie the Scientist* and *Millie the Mathematician* – two innovative 24-book STEM-themed learn-to-read series targeting early years literacy and engagement with science and mathematics across Australia. Using Kanter's six principles of Collaborative Advantage (*excellence, importance, interdependency, co-investment, integration*, and *evolution),* the development and dissemination of these resources represent best practice in community-university partnerships.

With Rotary, the collaboration was built upon a 20-year history of joint engagement in science outreach. The collaboration embodied *excellence* through existing expertise of the *Science on GO!* team and the establishment of a Rotary Steering Committee, chaired by a past District Governor and former Dean of Education, and included three past school principals – facilitating curriculum alignment and quality assurance with a focus on school needs and educational priorities. The Rotary committee also ensured the project remained on track holding the *Science on the GO!* team to deadlines, milestones and outcomes (*integration*). *Importance* was shared by both parties, with literacy and STEM education identified as central priorities. *Interdependency* was evident in the mutual roles played with Griffith providing content and design, while Rotary facilitated community-based dissemination and promotion through its national networks of Districts and clubs. *Co-investment* was demonstrated by philanthropic donations and collective efforts to distribute sample packs to all 8,549 Australian primary schools. *Evolution* is exemplified by the changing nature and number of collaborative programs over a 20-year period, which continue to expand in scope and ambition.

The books were initially designed as 'take-home readers' and therefore targeted parental engagement as much as student engagement. As a result, and in parallel, a formal partnership with P&Cs Qld augmented the program's impact. Recognising the *importance* of parental engagement in early education, P&Cs Qld identified the project's strong alignment with their core mission of "parents as partners." Their organisational *excellence* brought direct access to parents and school communities, supporting the co-authoring and refinement of the resources through focus groups and testing. The *interdependency* of this relationship was vital, with Griffith drawing on P&Cs Qld's networks to provide feedback to ensure usability and relevance from a parent and community perspective. *Co-investment* was evident in shared dissemination efforts, including conference promotions, print and digital campaigns, and regional coordinator networks. *Integration* was formalised through an MoU between the two parties and *evolution* of the partnership was realised by a Griffith appointment to the Board of P&Cs Qld.

The outcomes of these collaborations have been impressive. Over 160,000 hard-copy books are now in circulation, with more than 2 million annual family readings projected. During COVID-19 the books were rapidly converted to digital form to facilitate home-schooling. The first month of school lockdown saw over 100,000 e-book downloads and thousands of YouTube views, showcasing the project's adaptability and public value. Feedback from schools, parents, and educational leaders consistently highlights improved STEM interest, literacy engagement, and the transformative impact of female role models in STEM.

These strategic alliances reflect a truly synergistic model of community engagement, with Griffith University, Rotary, and P&Cs Qld co-creating new value together and a lasting educational impact for young Australians and their parents.

4.6 Inclusivity and Accessibility

This principle recognises the need to broaden participation and increase aspirations in STEM, particularly from underrepresented groups, including Indigenous communities, girls, individuals from low socio-economic status (SES) backgrounds, and rural and remote communities.

Policymakers, educators, and researchers have been addressing this challenge for years. However, despite sustained efforts and considerable investment, entrenched patterns of underrepresentation in post-compulsory STEM education and the STEM workforce persist (Archer et al., 2020).

4.6.1 Why address inclusivity and accessibility?

Addressing inclusivity and accessibility in community science programs is both an ethical obligation and a practical necessity. Programs with a focus on inclusivity and accessibility promote social empowerment by allowing equitable participation in scientific endeavours. They also broaden scientific literacy (enhancing the STEM pipeline) and they strengthen public trust in science. The introduction of diverse perspectives through broadening participation also improves the educational quality of engagement programs and improves general program outcomes, including long-term sustainability and scalability.

The following sections explore the rational for inclusivity and accessibility in greater detail.

Inclusivity and Accessibility as Democratic Imperatives: Community science engagement programs should be grounded in a normative commitment to equality and democracy (see Section 3.1.3 above). Researchers have long argued that science is not just for experts, but for everyone, and all citizens should have the chance to participate in scientific endeavours and shape the discourse and decision making around applications of science in society (Irwin, 2015; Stilgoe et al., 2014; Wynne, 2006).

Community science engagement also promotes scientific literacy, enabling citizens to understand complex issues and make informed decisions (Brossard & Lewenstein, 2009). By actively involving underrepresented communities, it ensures that all segments of society can both benefit from, and contribute to, scientific advancements. Incorporating diverse voices and perspectives can also help to align scientific research with the values and concerns of the broader community, empowering individuals as active civic participants rather than passive recipients of knowledge (Stilgoe et al., 2014).

Broadening Scientific Literacy and STEM Pathways: Inclusion and accessibility are practical necessities for education and workforce development. Increasing the STEM pipeline is essential for driving economic innovation, improving social mobility, and equipping individuals to be informed, scientifically literate 21st century citizens (Qld-State-Govt., 2024).

Australia's future workforce depends on a larger and more diverse pool of young people pursuing post-compulsory school studies in STEM, and *"we cannot afford to lose anyone; we must harness the potential of all people with a curious mind, a spark for problem-solving and a keenness to build up and change our world"* (Bergman et al., 2023). When access is open to all, more people can develop scientific literacy and therefore pursue STEM studies and STEM careers, benefitting society with a larger and more diverse talent pool.

Pandya (Pandya, 2012) emphasises that broadening participation means moving beyond the "usual suspects" to a more inclusive STEM landscape. However, studies show that many science engagement programs and institutions primarily attract those who are already well-educated, affluent, and from majority groups (Bevan et al., 2020; Dawson, 2014; Feinstein & Meshoulam, 2014). Dawson's study of science museums and science centres in the UK and US (Dawson, 2014) found that *"at present,* [these] *institutions are not inclusive spaces"*, with visitors tending to be affluent, white, and urban, while working-class, minority ethnic, and rural populations are underrepresented. Data from the most recent ASPIRES surveys support this notion with analysis from DeWitt et al. (DeWitt & Archer, 2017) concluding that *"despite efforts to widen participations informal science learning (environments) remain marked by privilege, suggesting a critical need for sustained equity work"*.

THE VALUE OF DIVERSE PERSPECTIVES: Another compelling reason to address inclusion and accessibility is the clear benefit to learning and innovation when diverse audiences and diverse perspectives are addressed.

In scientific research, diversity has been shown to improve the quality of knowledge produced. A review by Brouwer et al. (Brouwer & Hessels, 2019) outlines several ways citizen science programs enhances science and the generation of new knowledge. Crucially, the participation of underrepresented groups (such as women, Indigenous peoples, and minorities) helps *"reverse skewed representation in the production of knowledge"*, which in turn increases both the quality and legitimacy of that knowledge.

In the Australian context, there are many examples of Indigenous knowledge contributing to solving contemporary problems including application to threatened species, fire management, aquatic ecosystems and climate change (see for example (Ens et al., 2015) and references therein) and (Green et al., 2010; McLean, 2010; Prober et al., 2011). Incorporating Indigenous knowledge is both an ethical obligation and a way to improve science as people with deep ties to their environment can provide first-hand observations and insights that traditional scientific approaches might miss.

In educational settings, inclusive engagement isn't just "nice to have", it overtly improves educational outcomes by creating a richer learning environment where participants learn from each other's diverse perspectives, sharing different ways of thinking, knowing and problem solving.

TRUST AND LEGITIMACY: Inclusivity and accessibility are also crucial for building public trust in science (Gilfedder et al., 2019; Goud et al., 2023; Intemann, 2023; OECD, 2024; Skarlatidou et al., 2024). When only narrow audiences are involved in science and science engagement programs, others may feel alienated or suspicious of scientific institutions. By contrast, inclusive engagement invites people into the process, promoting transparency and mutual respect. A recent Organisation for Economic Cooperation and Development (OECD) science report (OECD, 2024) notes that *"transparent and inclusive engagement practices are needed to increase legitimacy"*, further noting that "*one-way communication from experts to a passive public is no longer sufficient*".

Laypeople often must rely on experts' knowledge, so some degree of trust is *"crucial for being an educated individual"* (Vaupotič et al., 2021). However, if certain communities are not exposed to science or feel excluded or unheard by science, that trust erodes. A recent public consultation found that distrust of science is often "*the product of lacking representation, inclusion, and engagement*" – especially among groups with histories of marginalisation (Goud et al., 2023). However, when individuals actively participate in scientific investigations (such as with authentic hands-on experiential learning or citizen science projects), they gain a deeper understanding of scientific methods, and a stronger sense of connection to the scientific community, thereby promoting greater trust in science overall (Gilfedder et al., 2019; Intemann, 2023; Skarlatidou et al., 2024).

IDENTIFYING SYSTEMIC BARRIERS: Despite the practical benefits and moral imperatives described above, significant systemic barriers continue to hinder participation in STEM engagement programs. These barriers can be practical barriers, or they may be barriers associated with the science capital of individuals (e.g. cultural/familial barriers or barriers of perception or attitude).

On the practical side, financial constraints and geographic isolation are common impediments. Attending a science camp or museum might be impossible for a low-income family if there are fees or travel costs involved – *"people living in poverty struggle to afford a science centre visit,"* (Dawson, 2014).

Distance is another factor. Rural and remote communities generally lack nearby science centres, museums, universities, or STEM clubs. Data from the UK and U.S. show that those *least* likely to visit informal science institutions include people in rural areas or far from cities, as well as individuals not in school or without family support for such outings (Dawson, 2014).

Even when cost and distance are not an issue, attitudinal barriers related to low science capital can persist. For instance, a person might feel "science isn't for me" or have low interest due to negative past experiences. These barriers typically stem from deeper issues of representation and inclusion. If someone never sees their culture or community's knowledge reflected in science media or science studies, they may be, understandably, disengaged.

Indeed, inadvertent cultural biases within institutions have historically made certain groups feel unwelcome – perpetuating the Mathew Effect.

The Mathew Effect in community-based science engagement programs: The Matthew Effect is a term that describes how advantages tend to accumulate for those who already have them, while disadvantages persist for those with fewer resources. It is often summarised as *"the rich get richer and the poor get poorer."* The term was coined by sociologist Robert Merton (Merton, 1968) with reference to a biblical passage from the Gospel of Matthew (Matthew 25:29):

"For whoever has will be given more, and they will have an abundance. Whoever does not have, even what they have will be taken from them."

Merton's study focussed on the allocation of resources and rewards to scientists based on their already successful contributions to science (Merton, 1968), but has been applied to a range of societal domains including business, technology, education and socioeconomic status.

Many studies (Bevan et al., 2020; Dawson, 2014; Farrell & Medvedeva, 2010; Feinstein & Meshoulam, 2014) have suggested that current community-based science engagement programs and institutions inadvertently perpetuate the *Matthew Effect* by primarily attracting and benefiting those who already have high science capital, such as children from well-resourced schools, urban areas, and families with a history of STEM engagement. This can happen through assumptions made during engagement activities, the language used by facilitators and in printed material, and the cost and location of the program.

These issues reinforce existing disparities, as individuals from underrepresented or marginalised communities, who may lack financial resources, role models, or prior exposure to science, face greater barriers to participation. Without intentional efforts to remove systemic barriers (e.g., cost, geographic isolation, cultural biases), these programs risk widening the gap rather than bridging it.

To counteract this, programs must critically examine how their programs might inadvertently exclude (through cost, location, format, or tone) and then proactively design for inclusion, ensuring that program design and funding initiatives prioritise those with the least access to STEM opportunities.

Ideas and resources for achieving this are presented in the following section.

4.6.2 How to address inclusion and accessibility

Broadening participation in STEM requires more than simply expanding access and opportunities (Bevan et al., 2018, 2020; Dawson, 2014; Feinstein & Meshoulam, 2014; Philip & Azevedo, 2017). Approaches that focus on these factors, fundamentally *"represent an uncritical perspective on the question of which people participate in STEM programs and why"* (Bevan et al., 2020). For example, replicating opportunities in different geographic and demographic locations, or making them low cost (or no cost), does not fully address the problem (Bevan et al., 2020; Dawson, 2014; Feinstein & Meshoulam, 2014).

Such an approach fails to consider whether community science engagement programs, intentionally or not, may be structured in ways to reinforce existing patterns of STEM participation (i.e. the "Mathew Effect" discussion above). Furthermore, this approach places the burden of participation and belonging on individuals in under-represented groups (Bevan et al., 2020) – an approach not widely favoured, for example in the Australian government's *Pathway to Diversity in STEM* report (Bergman et al., 2023) – *"people underrepresented in STEM too often carry the weight of advocating for change … these individuals should not have to change to belong and thrive"*.

Addressing inclusion and accessibility requires overt strategies to identify and overcome the systemic (largely cultural) barriers identified above. Retrofitting equity and inclusion approaches into programs that were not designed for such purposes is challenging and requires extensive and extended attention (Bevan et al., 2020). Rather, program designers should intentionally plan for equity at every stage of program design and delivery, in the same way they plan for program content and logistics.

Below are several approaches, drawn from research and experience, to facilitate inclusion and accessibility in science engagement programs.

UNDERSTAND YOUR AUDIENCE'S SCIENCE CAPITAL: Before launching or re-designing a program, it is necessary to assess the baseline knowledge, attitudes and cultural resources that target audiences have regarding science. Evaluation tools, like those documented in Chapter 4.2.2, that target general or specific audience segments (e.g., students, parents, teachers et.) should be employed to identify gaps and needs as part of the program's pre-evaluation process.

This information should subsequently inform the program's overarching goal(s) and objectives. For example, if the overarching goal of a program included *'increasing scientific literacy and critical thinking skills'*, then it would be prudent to pre-evaluate participant baseline understandings by using tools from Chapter 4.2.2 such as:

- *Test of scientific literacy skills (TOSLS)*
- *Science Process Skills Inventory (SPSI)*
- *Critical Thinking in Everyday Life Tool.*

The information garnered from these tools could then be used to assist in articulating (or modifying) specific objectives aligned to scientific literacy and critical thinking.

This data-driven approach ensures that inclusion and accessibility are not just lip-service slogans but are built into the program's targets and evaluation.

Staff Capabilities – Cultural Competency and Sensitivity: Bevan et al. (Bevan et al., 2018) posit that inclusive science engagement "*should be conceptualised as a process of cultural exchange, rather than as a process of translation*". This requires of program leaders and facilitators the development of relevant cultural competencies and sensitivities. This can start with the professional development of staff and volunteers to be aware of their own biases and to understand the backgrounds of the people and community they serve.

Broadening participation toolkit: To assist with staff development in this area, the *Centre for Advancement of Informal Science Education* (CAISE)[1] has produced an excellent resource designed to help community science engagement programs make their programs more inclusive and accessible (see (Bevan et al., 2020)). It provides a structured approach to staff training by "*encouraging reflection, discussion, and action on equity and inclusion*".

Key insights and resources from the CAISE toolkit include:

- Understanding the need for inclusive science engagement
    - as noted above, many science engagement programs inadvertently reinforce existing inequalities
    - the tool kit urges program leaders to critically examine their program designs and move beyond superficial inclusivity approaches of just increasing access and opportunity.
- Resources and conversation guides, including the following titles
    - Challenging Dominant Cultural Norms in STEM
    - Shifting from a "Pipeline" Model to a "Pathways and Agency" model
    - Engaging Communities in Co-Design
    - Addressing Barriers Beyond Access
    - Rethinking Parent and Community Engagement.
- A structured four-step framework for staff development, involving
    - a Read-and-Reflect component
    - stakeholder buy-in
    - structured group discussions
    - Action planning and implementation.

The CAISE toolkit is designed to be used for *Program Design*, *New Staff Orientation*, *Ongoing Professional Development*, and *Ongoing Evaluation and Continuous Improvement*.

[1] N.B. CAISE (the Centre for Advancement of Informal Science Education) ceased activities in 2022. Leadership of the USA's National Science Foundation's Advancing Informal STEM Learning (AISL) program has transitioned to the Reimagining Equity and Values in Informal STEM Education (REVISE) Centre. REVISE continues to support and advance the informal STEM education field by curating and managing "InformalScience.org", where a comprehensive repository of CAISE resources now resides. This platform includes project descriptions, research articles, evaluation reports, and tools dating from the 1980s to the present.

CO-DESIGN AND CO-DELIVER PROGRAMS *("NOTHING ABOUT US WITHOUT US")*: Inclusivity requires working '*with*', not just '*for*' communities. Often community engagement programs start with a top-down design process, seeking to 'serve' a community from the perspective of an already existing program. This can lead to important local community assets and local contexts being ignored or simplified or misrepresented (Bevan et al., 2018).

Chapter 4.4.2 highlighted the importance of co-design, community ownership and building local capacity and capabilities. When programs are co-designed and co-delivered, cultural relevance and inclusivity is more readily achieved, leading to more robust, sustainable programs (Barnes et al., 2022). Participants will see their own culture and local context reflected in the activities and outcomes, which encourages a sense of belonging.

However, co-design means moving beyond token consultation to genuine collaboration – where *"new value is created together"* (Kanter, 1994). Identifying local champions – educators, Elders, youth leaders and elected representatives – and ensuring they have input to planning meetings is essential. Their ideas need to be listened to, and their values and traditions need to be incorporated. This can be achieved in context by following Kanter's six key principles of collaborative advantage (excellence; importance; interdependence; co-investment; integration; evolution).

The CAISE toolkit guides (described above) can also assist with practical implementation of co-design principles. In addition, approaches for assessing community assets as a basis for establishing a community vision and co-designing programs in underrepresented groups is presented in Chapter 5.7 – *Leverage Local Knowledge, Contexts and Resources*.

Representation Matters: Role models count! – especially for young girls (AAS, 2019) and non-dominant cultures (Gladstone & Cimpian, 2021; Jackson et al., 2016). When youth see themselves represented in STEM contexts, they are more likely to aspire to STEM careers (Archer et al., 2012b; Archer et al., 2014; Archer et al., 2020). Involving community members as co-designers, co-facilitators or co-researchers can be transformative. Having diverse staff leading and delivering the program signals inclusion. Rather than an outside 'expert' running everything, locally trained volunteers, educators or scientists can be used, or they can be invited as guest speakers. This shared responsibility not only builds local capacity and inclusivity but also builds trust – the foundation of program sustainability.

Finally, patience and persistence are required virtues; building trust with communities that have been historically excluded takes time. The overarching principle is *'nothing about us without us'.* By treating community members as equal partners, program designers can ensure that inclusion is not an afterthought – but rather a deliberately embedded principle from the start.

REMOVE OR REDUCE PRACTICAL BARRIERS: A concrete step toward accessibility is to lower the financial costs and practical inconvenience of participation. Studies on broadening participation often point to seemingly small hurdles (e.g. lack of public transport or a $10 fee) that can disproportionately affect those from underprivileged backgrounds.

Financial costs: If there are fees, provide bursaries or make events free whenever possible – lack of money should never be the reason someone is excluded. Even covering small expenses (notebooks, travel, lunch) can make a difference for low-income participants.

Distance: Transportation is another factor. Consider hosting programs *in* the communities you aim to engage with, rather than expecting everyone to come to a city centre or university campus. Mobile science labs, traveling workshops, or partnerships with local schools and libraries can bring STEM experiences to rural and remote areas. If in-person access is tough, provide remote options – online webinars, virtual citizen science projects, or take-home science kits.

Timing and physical access: When programs are held is also part of accessibility. Offering events on weekends or evenings, and providing childcare if needed, can remove significant participation barriers. Additionally, ensure disability access by choosing wheelchair-accessible venues.

While these practical accommodations can send a message that everyone is welcome and that access is facilitated for many, it needs to be remembered that the major concerns with lack of diversity in community science programs are associated with cultural and personal perceptions of inclusivity and a sense of belonging (i.e. science is "not for me"). Program designers need to place a high priority on addressing these barriers alongside the practical barriers.

CULTURALLY RESPONSIVE PEDAGOGIES – A FIRST NATIONS PERSPECTIVE: Culturally responsive approaches to education and learning are crucial for community science engagement to ensure that program learnings are relevant and meaningful for diverse audiences. This is particularly important in the Australian context when engaging with First Nations communities.

Traditional Western science education often excludes Indigenous knowledge systems, reinforcing barriers to participation and engagement (Ah Chee et al., 2024). Programs should therefore acknowledge and incorporate longstanding scientific practices, as well as ways of knowing and learning, that have been integral to (for example) sustainable land management for tens of thousands of years. This will build trust with First Nations communities and enhance participation and learning outcomes (Ah Chee et al., 2024).

Adopting appropriate frameworks and resources: Desktop searches using search terms such as *First Nations education, Australian Indigenous education*, *First Nations perspectives in Australian education* and *Indigenous Australian pedagogies* will yield a wealth of insights and resources. To assist in focussing efforts from a pedagogical perspective, two useful resource sets are briefly discussed below.

1) A Guide for Curriculum Development: First Nations Australians' Science (Ah Chee et al., 2024)

The Guide for Curriculum Development (Ah Chee et al., 2024), created under the auspices of the Australian Council of Deans of Science, provides a framework for integrating First Nations Australians' knowledge and histories into science education programs. Developed through a collaborative co-design process between both First Nations and non-First Nations academics, this is based on the seminal work of Professor Joe Sambono. It serves as a tool for educators to ensure Indigenous perspectives are meaningfully embedded in science education, promoting reconciliation, equity, and scientific excellence. Key features include:

- advice on incorporating Indigenous knowledge into science curricula and education programs
- a set of guiding principles for educators
- a set of practical implementation strategies, and
- a set of case studies and best practices.

2) 8-Ways of Aboriginal Learning (Yunkaporta, 2009; Yunkaporta, 2010)

"Aboriginal perspectives are not found in Aboriginal content, but Aboriginal processes…" [2]

Facilitating student learning in science requires educators and program facilitators to ensure their approaches align with *how* people learn (Gilbert, 2005; John D. Bransford et al., 2000; M. Suzanne Donovan et al., 1999). This fundamental tenet underpins learning and teaching approaches for *all* students[3].

[2] Extracted from 8-Ways

[3] N.B. Aligning program design and delivery to *how people learn* is elaborated in detail in Chapter 5.1 (Incorporate Inquiry Based Learning Approaches)

The 8-Ways framework (Yunkaporta, 2009; Yunkaporta, 2010) articulates eight ways of Aboriginal learning. It is a widely recognised pedagogical approach that aligns Aboriginal ways of learning with educational practice by incorporating eight interconnected pedagogies aligned to each of the eight ways of Aboriginal learning (see Table 4.6.1). Rather than focussing on *what* to teach, it guides educators in embedding First Nations perspectives through *how* they teach – emphasising Aboriginal ways of learning such as storytelling, land-based learning, and visual mapping.

Table 4.6.1 The eight interconnected pedagogies of 8-Ways learning (adapted from 8-Ways)

Pedagogical Label	Brief Description	Connection to Aboriginal Ways of Learning
Story Sharing	Narrative-driven learning (telling a story)	By connecting through stories shared
Learning Maps	Visualised learning processes (making a plan)	By picturing pathways of knowledge
Non-verbal	Hands-on/reflective techniques (thinking and doing)	By seeing, thinking, acting, making and sharing without words
Symbols and Images	Use of symbols/metaphors (drawing it)	By keeping and sharing knowledge with art and objects
Land Links	Land-based learning (taking it outside)	By working with lesson from land and nature
Non-linear	Indirect/synergistic logic (trying a new way)	By putting different ideas together and creating new knowledge
Deconstruct/ Reconstruct	Modelled/scaffolded genre mastery (watching first then doing)	By working from wholes to parts, watch then doing
Community Links	Connectedness to community (sharing it with others).	By bringing new knowledge home to help the mob

By understanding and applying these eight interconnected pedagogies, program facilitators can deliver core scientific content in ways that resonate with First Nations worldviews and relationships to knowledge and Country. This approach enables more inclusive and meaningful engagement, supports improved learning outcomes, and fosters authentic, respectful science education with First Nations communities knowing. (see also (Harrison & Skrebneva, 2020) *and references therein*). Professional development and training in these pedagogical approaches is available by registering interest on the 8-Ways web-portal.

The notion of 'First Nations science capital' – implications for community science programs: A recent study by Cooper et al. (Cooper et al., 2024) introduces the concept of *First Nations science capital* and proposes that *"First Nations science is a distinct and valuable form of science capital that* **all** *students should engage with"*. They further argue for its recognition as a legitimate and essential form of science knowledge that should be embedded into the mainstream Australian curriculum.

The authors define First Nations science capital as the science-related knowledge, practices, and ways of knowing held by First Nations peoples, such as knowledge of astronomy, land management, bush medicine, sustainability, and weather patterns. It also encompasses the culturally unique ways of learning, understanding and engaging with the natural world, *"along with a range of science-related skills and knowledge transmitted across generations within First Nations communities"* (Cooper et al., 2024).

Like non-Indigenous students, the development of science capital for First Nations students is shaped by what they know, what they do, what they believe and who they know – and these forms of capital are significantly influenced by how and what they learn. Copper et al. (Cooper et al., 2024) contend that the current Australian curriculum favours dominant (white, Western, middle-class) forms of science capital, and under-recognises those forms of science capital held by First Nations students – ultimately contributing to disengagement and inequity.

An opportunity therefore exists for community science programs to address these concerns by connecting with formal education providers (see Chapter 5.6) to influence First Nations science capital by adopting culturally responsive pedagogical approaches such those outlined above. Furthermore, connecting community programs to *Country* (see Chapter 5.7) will not only make learning more meaningful, it can help to dismantle barriers to participation, promote equity and increase the STEM aspirations of First Nations students.

ADDITIONAL RESOURCES: Additional resources to assist with practical implementation of diversity, inclusivity and accessibility (including resources relating to Indigenous perspectives) can be found in **Appendix F**.

4.6.3 Case study: NISEP – Culturally responsive community engagement

The National Indigenous Science Education Program (NISEP) is a collective of Aboriginal Elders, university academics and high school teachers. The program seeks to increase the number of Indigenous students completing secondary education and pursuing tertiary education or employment, particularly in STEM fields. The program was developed after Indigenous Elders approached Macquarie University to help build interest in STEM among young people. Since 2005, NISEP has trained more than 1000 Indigenous students as STEM leaders, in science-based activities, ranging from microscopy to polymer chemistry, which they then present to younger students within their schools and feeder primary schools. By training the STEM leaders, the program is creating relatable science communicators, it supports the education and capability of the STEM leaders, many of which have gone on to further education.

NISEP also plays a critical role in connecting Indigenous knowledge systems to Western science. Through school and community-based events, traditional knowledge of bush foods and medicines are integrated with contemporary scientific practises, highlighting the relevance and importance of retaining Indigenous knowledge. These events showcase Indigenous and Western science to hundreds of participants, developing cross-cultural understanding and appreciation for diverse scientific perspectives. NISEP is a national leader and exemplar for STEM inclusivity and accessibility and, was awarded the 2019 Eureka Prize for STEM Inclusion.

5.0 Best Practice Science Engagement Principles

The previous chapter provided details on best practice core (or generic) design principles for community engagement programs. This chapter focuses best practice *science engagement* principles for designing and delivering community science engagement initiatives.

Each principle aligns to one or more of:

- the Eight Dimensions of Science Capital (Archer et al., 2016); and
- the four goals outlined in Chapter 1.

5.1 Incorporate Inquiry-Based Learning Approaches

Inquiry-based learning (IBL) approaches have become central strategies for effective science engagement, particularly in informal educational settings, such as community science programs (Harnik & Ross, 2004; Jacobs et al., 2015; Luehmann, 2009; McCauley et al., 2018; Redman et al., 2021; Valle et al., 2021; Zack et al., 2017). By engaging participants in the processes of questioning, investigating, and reasoning, IBL mirrors scientific inquiry (i.e. the way science is done), encouraging participants to think and act like scientists, while promoting deeper understanding of scientific concepts and ideas. When applied to community science engagement programs, IBL enhances participants' ability to critically evaluate information and apply scientific knowledge to real-world contexts, leading to improved scientific literacy (Aulia et al., 2018; Gormally et al., 2009; Kang, 2022; Laugksch, 2000; Miller, 1998), problem-solving abilities, and critical thinking (Alsaleh, 2020; Barrow, 2006; Council, 2000; Friesen & Scott, 2013; Sam, 2024).

5.1.1 Why do it? – theoretical foundations of inquiry-based learning approaches

IBL approaches work because they align closely to how people naturally learn. In a series of seminal publications, synthesising decades of research relating to how people learn, the National Research Council (USA) highlight the importance of aligning educational practices with findings from cognitive and learning sciences (Gilbert, 2005; John D. Bransford et al., 2000; M. Suzanne Donovan et al., 1999). Three core principles are proposed as the foundation for facilitating learning, namely: engage prior knowledge; *foster deep conceptual understanding;* and *promote metacognition.*

1. Engaging prior knowledge: learners begin with what they already know, including accurate understandings of scientific concepts and potential misconceptions. These preconceptions significantly influence how new information is absorbed and how new knowledge is constructed. Social constructivist learning theory (Piaget, 1952) posits that learning is an active, social process where individuals construct their own knowledge through interactions with others, and compare and relate new information with prior understanding. Learners evaluate, accept, or reject new ideas and information based on how well these align with their existing cognitive and social frameworks.

In practice, this requires science engagement programs to actively elicit, assess and engage with participant knowledge at the start of the engagement process (M. Suzanne Donovan et al., 1999). Connecting new material to learners' existing knowledge makes learning more meaningful, promoting improved retention and deeper conceptual understanding.

2. Fostering deep conceptual understanding: effective learning of scientific concepts requires more than memorising facts – it involves organising knowledge into well-structured conceptual frameworks. These frameworks allow learners to understand the big picture, relating different concepts to one another, and applying knowledge in novel situations (John D. Bransford et al., 2000).

In practice, this requires the design of activities where learners analyse, synthesise, and evaluate information rather than just recall it. The emphasis should be on depth of conceptual understanding rather than breadth of knowledge (Gilbert, 2005; M. Suzanne Donovan et al., 1999). Thankfully, this is easier to achieve in community engagement programs compared to formal school settings where the need to cover a wide range of curriculum topics often leads to limited time and shallow learning. Community science activities typically target a limited range of scientific concepts, allowing program designers to include deliberate redundancy – for example, via the use of multiple representations of the same concept at work, using multiple modes of representation – leading to deeper conceptual understanding (M. Suzanne Donovan et al., 1999; Prain & Tytler, 2012; Treagust, 2008; Tytler & Hubber, 2016).

3. Promoting metacognition: Metacognition, often referred to as thinking about one's own thinking, is crucial for effective learning. In formal learning settings (e.g. schools), students who develop metacognitive skills perform better academically (Muijs & Bokhove, 2020; Perry et al., 2019). Facilitating the development of metacognitive skills is therefore a key component of quality learning programs. Studies consistently show that IBL approaches are effective in promoting metacognition and therefore deep learning (see (Schraw et al., 2006) and references therein)).

Metacognitive skills include:

- being self-aware of what is known and unknown as well identifying one's own strengths and weaknesses in a specific task or project
- being able to monitor one's own learning and adjust learning strategies accordingly
- actively reflecting on thought processes and critically analysing the effectiveness of strategies and approaches after completing a task
- setting clear and achievable goals and planning approaches to meet them
- prioritising time and tasks to meet learning goals, and
- understanding not only what is known (cognitive domain) but also understanding how one knows what they know (metacognitive domain).

In practice, this requires the design of science engagement programs that, wherever possible, allow participants to:

- ask questions and/or set tasks that are engaging and relevant to them
- plan strategies to answer the question and/or achieve those tasks
- predict outcomes in advance
- experiment with different approaches using both collaborative and cooperative learning approaches, and
- undertake reflective practices to help them evaluate their own approaches to, and progress in, learning.

5.1.2 How to do it – practical implementation of IBL approaches

IBL approaches in community science engagement programs place the participant at the centre of the learning process. At its core, inquiry involves the asking and answering of questions. When those questions are asked and/or answered by the participants themselves, they will be more engaged, more motivated, and more likely to achieve the desired outcomes (Bayram et al., 2013; Buchanan et al., 2016; Gholam, 2019). To promote this level of engagement, it is essential that participants are actively involved in a dynamic inquiry process where, ideally, they have ownership over how they approach answering questions or solving problems. By determining their methods and strategies, participants develop a sense of agency, increasing intrinsic motivation and commitment.

IBL approaches also encourage participants to construct their own understanding of concepts first (engaging in hands-on exploration and critical thinking), ***before*** being exposed to instructor-led explanations. This sequencing ensures learning is a pathway of personal discovery. Ideally, however, that pathway should not be an individual pathway and collaboration with peers is strongly encouraged. Working in teams allows participants to share diverse perspectives, refine ideas through discussion, and practice effective communication and teamwork skills. This collective effort not only enhances the depth of inquiry but also builds a sense of community and shared achievement.

Readily Implemented Inquiry-Based Learning (IBL) Frameworks: A recent systematic review of IBL frameworks (Pedaste et al., 2015) showed that the diverse and inconsistent terminology used to describe inquiry activities often confuses novice science program designers. This lack of clarity can hinder their ability to identify the core phases and processes of IBL, increasing the risk of failure in their initial efforts to develop effective community engagement programs. For this reason, this report focuses on frameworks that have demonstrated widespread success and are straightforward to implement.

Table 5.1.1 lists several well-established, evidence-based, IBL frameworks that have been successfully employed in science engagement and science education programs to promote scientific literacy and encourage critical thinking. These frameworks are simple in structure and readily implemented by novice science engagement program designers and deliverers. All frameworks emphasise participant-centred active engagement, are curiosity-driven, involve hands-on exploration, align with the way 'real science' is done, and include critical thinking and critical reflection components.

Table 5.1.1 Selected evidence-based IBL frameworks used in science education and community science engagement programs*

IBL Framework	Notes	Selected References
POE/PEE **P-POE/P-PEE**	POE – predict, observe, explain PEE – predict, explore, explain P-POE – plan, predict, observe, explain P-PEE – plan, predict, explore, explain	(Haysom & Bowen, 2010; Samsudin et al., 2021; Treagust et al., 2014; White & Gunstone, 2014)
5 E's	Engage, Explore, Explain, Elaborate, Evaluate	(Bybee et al., 2006; Bybee, 2014; Polanin et al., 2024)
7 E's	Elicit, Engage, Explore, Explain, Elaborate, Extend, Evaluate	(Eisenkraft, 2003) (Balta, 2016)
LIA	Launch, Inquire, Action	(PrimaryConnections, 2024)
REACT	Relate, Experience, Apply, Cooperate, Transfer	(Jannah et al., 2020; Mutlu, 2023)

* See (Pedaste et al., 2015) for a comprehensive list of IBL Frameworks, IBL Cycles and IBL Phases

Importantly, these frameworks are underpinned by a cognitive scaffolded approach (Flick, 2000; Lin et al., 2011; van Uum et al., 2017) where learners are guided through different phases of the inquiry process, such as identifying problems, generating hypotheses, designing investigations, analysing data, and drawing conclusions (Pedaste et al., 2015). In this way, learners progressively build confidence and competence. Initially, scaffolding might involve providing explicit guidance at the outset, for example, posing initial questions or demonstrating methods or concepts (Arnold et al., 2014). As confidence and competence grows, facilitated guidance and support is gradually withdrawn, allowing participants to take ownership of their learning (Aero, 2024). This balance ensures that learners are challenged while avoiding frustration or disengagement.

All of the frameworks listed in Table 5.1.1 incorporate the principle of "Explore before Explain" which is fundamental to participant-centred engagement in science (Brown, 2020, 2024). When participants engage with scientific concepts through exploration *before* receiving formal explanations, they are able to construct their own understanding based on firsthand experience. This process encourages curiosity, promotes critical thinking and helps build stronger connections to new knowledge. In a recent systematic review of IBL frameworks (Polanin et al., 2024) concluded that *"our findings confirm the importance of students (a) actively exploring scientific phenomena, prior to being introduced to scientific explanations, (b) developing their own explorations based on evidence, and (c) applying their evolving explanations to new and novel situations".*

It should also be noted that the literature is replete with dozens of additional IBL frameworks that have been employed in science outreach and science education programs, many of which are addressed in the systematic reviews of (Pedaste et al., 2015), (Polanin et al., 2024) and (Joswick & Hulings, 2023).

Two of the IBL frameworks listed in Table 5.1.1, POE and 5E's, are elaborated upon below, with an emphasis on practical application and implementation strategies. These have been chosen due to their proven effectiveness, ease of implementation, and accessibility for a wide range of audiences. Additionally, information on the LIA framework is provided in **Appendix G**[4].

THE PREDICT OBSERVE EXPLAIN (POE) FRAMEWORK: For organisations and individuals new to developing and implementing community science engagement programs, starting with the POE framework (or its adaptations) can be an effective approach – particularly if the target audience is young and/or has had limited past opportunities to engage with scientific concepts.

The **Predict-Observe-Explain (POE)** instructional strategy is an IBL approach designed to actively engage participants in the learning process by encouraging critical thinking, reflection and science process skills (Kearney et al., 2001; Mirabueno, 2023; White & Gunstone, 2014). The POE strategy has three discrete stages:

1. Predict – participants make predictions about the outcome of an experiment, observation, or phenomenon based on their prior knowledge and current understandings. There are some simple ways to facilitate participant predictions, for example:

1. **"I think ...":** *"**I think** if we place a plant in the dark its growth will slow."*
2. **"If ... then ... ":** *"**If** we place a plant in the dark, **then** its growth will slow."*
3. **"If ... then ... because ..."** ...*"**If** we place a plant in the dark, **then** its growth will slow down **because** plants need light to grow."*
4. **"We think ... because..."** ... *"We **think** the plant will grow taller **because** it is getting more sunlight and plants need sunlight to grow."*
5. **"If I change ..., then ... because ..."** *"**If I change** the type of soil, **then** the growth rate of the plant will change **because** soil composition affects nutrient availability."*

These approaches range in complexity and serve to elicit participants' preconceptions, revealing potential misunderstandings, while encouraging them to articulate their reasoning. The first example is a less formal, descriptive prediction, whereas the others adopt a more structured approach, identifying specific cause-effect relationships. Examples 3-5 introduce an additional explanatory component beyond the predictive component – allowing current understandings to be identified.

[4] N.B. The LIA framework is new. To the authors' knowledge, at the time of writing, it is the only readily available IBL framework that explicitly builds its instructional phases around the concept of science capital. This model is significant in the Australian context because it is set to be widely used in Australian schools as part of the new *Primary Connections* rollout in Australian schools over the coming years. See Appendix G for more detail.

The fourth example encourages collaborative prediction-making based on group consensus and shared reasoning. The final example connects experimental variables directly to expected outcomes, supporting a deeper understanding of experimental design.

By selecting prediction-making approaches tailored to the audience's needs and capabilities, facilitators can effectively engage participants, guiding them from simple descriptive predictions to more complex, evidence-based reasoning. In this way, facilitators can choose different approaches for prediction making (of varying complexity) to suit the needs and capabilities of the audience, potentially guiding them from simple descriptive predictions to more complex, evidence-based reasoning.

2. Observe – Participants observe a phenomenon, watch a demonstration or (ideally) conduct an experiment, to gather evidence. The focus for participants in this stage is making meaningful observations, by noting what *actually* happens, and collecting relevant data to provide a basis for analysis. Scientific notebooking (Collins & Fulton, 2017; Fulton, 2012; Miller & Martin, 2016; Paek & Fulton, 2021; Ruiz-Primo et al., 2004) or journalling strategies (Antink-Meyer et al., 2023; Plummer et al., 2010; Stone, 2020) can be used to record observations (cognitive domain) and to note initial thoughts about what has been done, why it was done that way, and what it could mean (metacognitive domain).

3. Explain – participants compare their observations to their initial predictions and attempt to explain any discrepancies or affirmations. The instructor then guides participants to connect their observations and (tentative) explanations to current scientific principles – enhancing critical thinking and communication skills – ultimately leading to deeper conceptual understanding.

Adaptions and more sophisticated extensions of the POE framework are described in **Appendix G**, including PEE (Predict-*Explore*-Explain), POEE (Predict-Observe-Explain-*Explore*), P-POE (*Plan*-Predict-Observe-Explain), and P-PEE (*Plan*-Predict-Explore-Explain), which engage learning in extra planning and/or exploring phases.

THE 5 E'S FRAMEWORK FOR INQUIRY BASED LEARNING: The 5E's inquiry-based learning (IBL) instructional model is a widely applied and effective framework that organises learning into five phases: Engage-Explore-Explain-Elaborate-Evaluate. This model offers a more sophisticated approach than simpler frameworks, like POE, due to its closer alignment with constructivist learning principles and its emphasis on active, participant-centred learning (Bybee et al., 2006; Bybee, 2014). It emphasises hands-on experiential learning, encourages active investigation and critical thinking for deep conceptual understanding. Additionally, it promotes the development of metacognitive skills through reflection and iterative learning processes, particularly during the Explain and Evaluate phases, where learners articulate and assess their understanding.

Each phase is designed to guide learners through a logical progression of inquiry and discovery, supporting the construction knowledge and applying it to new contexts.

Phases of the 5E's Framework

1. Engage: This phase aims to capture learners' interest and link new information to prior knowledge. It generally starts with a relatable hook activity that stimulates engagement and curiosity (McHugh & McCauley, 2017), preparing learners for further exploration (Bybee, 2014). This can come in the form of a thought-provoking question, a surprising phenomenon, or a demonstration that challenges prior knowledge or expectations. Discrepant events are often used – unexpected or counterintuitive phenomena that deviate from what participants anticipate will stimulate curiosity and motivate inquiry (Chin, 1992; González-Espada et al., 2010).

2. Explore: In this phase, participants actively investigate concepts through hands-on experiments, collaborative tasks, or guided/open investigations (see below). Cooperative and collaborative learning approaches are encouraged in this phase (Gillies, 2023; Korkman & Metin, 2021), and allowing learners to design aspects of the experimental design increases motivation and leads to greater engagement. This phase encourages critical thinking and foundational understanding, as learners make observations, collect data and identify trends and patterns (Marshall & Horton, 2011).

3. Explain: This phase focuses on helping learners articulate and refine their understanding of concepts they explored earlier. Learners consolidate their knowledge by discussing findings, constructing explanations, and connecting ideas to scientific principles. Instructors facilitate this process by guiding discussions, introducing formal terminology and scientific concepts, and addressing misconceptions. This phase fosters critical thinking and deepens conceptual understanding by encouraging participants to communicate their reasoning and reflect on their learning (Bybee et al., 2006; Tural et al., 2010).

4. Elaborate: In this phase, participants are challenged to extend their understanding by applying concepts just learnt to new situations or solving complex problems. This phase encourages critical thinking, creativity, and the transfer of knowledge to unfamiliar contexts, solidifying their learning (Duran & Duran, 2004). Through additional investigations, projects, or collaborative tasks, participants deepen their comprehension and explore interdisciplinary connections. Instructors act as facilitators by prompting further exploration and scaffolding the learning process (Bybee et al., 2006; Tural et al., 2010).

5. Evaluate: The final phase involves assessing understanding and reflecting on learning. Learners demonstrate their comprehension and identify areas for improvement through self-assessment, peer feedback, or instructor evaluation, developing metacognitive skills (Llewellyn, 2012). This phase ensures deeper conceptual understanding and informs future learning (Bybee et al., 2006; Tural et al., 2010).

SUMMARY OF THE BENEFITS OF INQUIRY-BASED LEARNING APPROACHES: Harlen (Harlen, 2013) provides an excellent summary of IBL approaches by recognising that the experience of developing understanding through one's own thinking and reasoning has many benefits which are not obtained in other ways. These include:

- enjoyment and satisfaction in finding out for themselves something that they want to know
- seeing for themselves what works rather than just being told
- satisfying, and at the same time stimulating, curiosity about the world around them
- developing progressively more powerful ideas about the world around
- developing the skills needed in scientific inquiry through participation in it
- realising that learning science involves discussion and working with and learning from others, and
- understanding science as the result of human endeavour.

These benefits extend to participants across a wide range of ages, backgrounds, and levels of science literacy, making these approaches particularly versatile for engaging diverse community audiences.

5.2 Hands-on Experiential Learning – Investigations and Experiments

The previous Chapter (5.1) outlined the theoretical foundations and introduced practical frameworks for implementing inquiry-based learning (IBL). These frameworks adopt the key principle of *Explore-before-Explain*. This Chapter focuses on the *Explore* component and specifically the rationale and practical implementation of *experimental investigations* in community science engagement programs.

5.2.1 Why do hands-on experiential learning? – theoretical foundations

Hands-on experiential learning in science, facilitated through scientific investigations and experimentation, is a key component of effective community engagement in science, promoting critical thinking skills, scientific literacy, and an understanding of the process of scientific inquiry.

Scientific investigations and experiments are conducted to explore phenomena, test hypotheses, solve problems, and generate evidence-based knowledge. Through systematic observations and experimentation, they uncover cause-and-effect relationships, validate theories, and develop solutions to real-world challenges, contributing to advancements in healthcare, medicine, environmental sustainability, climate change mitigation, agriculture, and renewable energy.

Incorporating investigations and experiments into community science engagement programs allows participants to develop skills such as:

- understanding of scientific concepts
- evidence-based scientific reasoning
- practical scientific skills and methodologies
- teamwork skills
- an understanding of the nature of science, and
- an interest in STEM, STEM studies and STEM careers.

Hands-on, experiential learning approaches draw on key theoretical and empirical insights, connecting theoretical concepts with practical, concrete experiences. Kolb's *Experiential Learning Theory* (Kolb, 1984) proposes that knowledge is created through the transformation of experience. In this model, participants actively engage with science through a cycle of concrete experience, reflective observation, abstract conceptualisation, and active experimentation. By interacting directly with materials and processes, learners transform experience into knowledge, reinforcing both conceptual understanding and practical skills (Abdulwahed & Nagy, 2009).

Research highlights the ability of experiential learning to spark curiosity, sustain motivation, and improve academic achievement (Alkan, 2016; Holstermann et al., 2010; Susiloningsih et al., 2023). These activities also promote active engagement, since the physical act of participating in experiments connects learners emotionally and intellectually to the material (Satterthwait, 2010).

A FOCUS ON EXPERIMENTAL INVESTIGATIONS: In the context of this document, *experimental investigations* are considered one of three forms of scientific investigations, alongside *descriptive investigations* and *comparative investigations*. While all three forms of scientific investigations are valid in community science engagement programs, the importance of understanding how to carry out *experimental investigations* is paramount for development of scientific literacy and critical thinking skills. For more information, **Appendix G** provides a comparative description of all three forms of scientific investigations.

Experimentation is considered a privileged means of confirmation (Currie & Levy, 2018) involving a unique combination of deliberate planning, manipulating of experimental parameters, observing, measuring, and interpreting – thereby creating a unique knowledge-creating capacity (Hansson, 2016). As a result, community members participating in experimental investigations, engage not only with scientific concepts, but also with the processes and procedures of scientific inquiry itself (i.e. the way science is done). Such engagement teaches critical scientific skills such as questioning, hypothesis generation, hypothesis testing, manipulation of materials and equipment, data analysis, and drawing evidence-based conclusions – key features of scientific literacy.

SCAFFOLDING EXPERIMENTAL INVESTIGATIONS: When designing and facilitating experimental investigations for community engagement programs, it has been shown that dividing (or chunking) the overall process into several learning phases is valuable for ensuring clarity, accessibility, and improving learning outcomes. Table 5.2.1. (adapted from (de Jong, 2006) and (Pedaste et al., 2015)) describes the five general learning phases for experimental investigations.

Breaking the overall experimental investigation process into digestible phases in this way, is important as it allows facilitation of cognitive scaffolding. Simply put, cognitive scaffolding involves helping participants "to solve a problem, carry out a task or achieve a goal which would be beyond their unassisted efforts" (Kawalkar & Vijapurkar, 2013; Wood et al., 1976). First introduced as an instructional strategy by Wood et al (Wood et al., 1976) cognitive scaffolding can take various forms, such as:

- Breaking tasks into smaller, manageable steps
- Providing hints, cues, visual aids or models to guide problem-solving
- Asking guiding questions and encouraging self-reflection.

The goal is to provide overt support and guidance to develop knowledge, skills and confidence, then gradually remove that support as the learner becomes more capable, eventually performing tasks or solving problems on their own (Aero, 2024).

Table 5.2.1 Learning phases for experimental investigation

Phase	Description	Sub-phase	Description
Orientation	The process of stimulating curiosity and learning about a topic and/or problem		
Conceptualisation	The process of generating testable statements and proposing hypotheses	*Questioning*	The process of generating testable research questions based on the stated topic/problem
		Hypothesis Generation	The process of generating hypotheses based on the stated topic/problem
Experimentation	The process of planning an experiment, collecting, analysing and interpreting databased on the experimental design	*Experimental Design*	The process of articulating variables, and designing procedural steps to allow conduction of an experiment to test a hypothesis
		Prediction	A specific explanative prediction statement referencing the dependent and independent variables
		Observations and Data Collection	The process of actively conducting the experiment, recording detailed observations and collecting data
		Data interpretation	The process of making meaning out of collected data and synthesizing new knowledge
Drawing conclusions	The process of developing evidence-based conclusions based on data evaluation and comparing with initial hypothesis and prediction		
Evaluation	Reflecting on and interrogating the reliability and validity of the overall investigation process	*Reflection*	The process of describing, critiquing, evaluating and discussing the experimental investigation. This involves an internal discussion with collaborative partners.
		Communication	The process of presenting outcomes of the experimental investigation to others and receiving feedback. This involves an external discussion with others.

5.2.2 Implementing hands-on experiential learning approaches – experimental investigations

Hilton et al. (Hilton et al., 2005) argue that laboratory or field-based, hands-on experiences connect learners directly with the material world, using tools, data, and models to investigate real-world phenomena. They further posit that these experiences are most effective when:

- they are designed with clear learning outcomes in mind
- they are thoughtfully sequenced, scaffolded, and integrated into broader instructional frameworks (e.g. 5E's)
- they are designed to integrate learning of science content with learning about the processes of science, and
- they incorporate ongoing reflection and discussion.

These approaches ensure that participants not only learn the "what" of science but also the "how" and "why," creating a holistic and impactful educational experience.

Participant Centred Experimental Investigations: Whenever possible, participants should generate their own ideas for investigation, focusing on topics that are interesting, relevant, and engaging to them. However, practical constraints such as limited resources, time restrictions, or specific objectives of the engagement process may make this impractical in some cases. To improve self-motivation and promote ownership of the experimental process, participants can still be empowered to contribute meaningfully by formulating their own testable questions and hypotheses, with guidance where necessary. They can also choose which variables to manipulate, measure, or control, ensuring their active involvement in shaping the investigation while working within the broader framework of the desired outcomes of the engagement program. Practical approaches on how to sequence and scaffold these ideas are provided in the following.

Practical Scaffolding of Experimental Investigations: The sections below provide high-level descriptions of key approaches to scaffolding experimental investigations for community science programs. For more detailed guidance, **Appendix H** offers a comprehensive collection of resources and practical examples to support program facilitators in effectively designing and implementing scaffolded investigative activities.

1. Orientation (engage phase): This phase involves introducing the "big ideas" relating to the purpose and context of the investigation with a view to sparking interest, curiosity and, ultimately, active engagement. The orientation phase lays the ground work for the rest of the investigation process by encouraging question formulation and setting of hypotheses (Bybee et al., 2006). In practice, the orientation phase of experimental investigations has significant overlap with the 'engage' phase of inquiry frameworks such as the 5E's framework.

Use hooks and/or discrepant events: Hooks, such as thought-provoking questions or intriguing visuals, can capture participants' attention and draw them into the investigation. Similarly, presenting discrepant events—unexpected phenomena that challenge existing knowledge—can create cognitive dissonance, motivating participants to resolve their curiosity through active inquiry and exploration. **Appendix H** provides practical resources and examples of engaging hooks and discrepant events.

2. Generation of testable questions and broad hypothesis statements: Participants propose testable statements and/or tentative explanations based on their prior knowledge and initial research/discussions during the orientation phase. Connecting prior knowledge and current understandings to potential outcomes encourages critical, evidence-based, thinking.

2.1 Testable questions: A testable question is a question that can be answered through experimentation by making observations and/or measurements. It focuses on something specific that can be measured (or observed) when something else is changed or altered in some way – i.e. cause and effect scenarios where participants need to identify experimental variables.

2.2 Hypothesis statements: A hypothesis statement is a broad, testable statement or educated guess that describes a phenomenon or relationship based on prior knowledge or observations.

Appendix H provides practical resources for generating testable questions and hypothesis statements and lists many examples that can be easily adapted to different contexts.

3. Experimentation: This phase can be broken into several sub-phases, including, Experimental Design (fair tests), Prediction, Observations and Data Collection, and Data Interpretation.

3.1 Experimental design/fair test – participants design and plan experiments to test their hypotheses. Ideally, they identify variables and controls, choose materials, and outline procedures, ensuring the experiment is structured for reliability and reproducibility. Identifying potential risks and/or ethical concerns could also be included.

Young participants in community science engagement programs may already be familiar with the concept of a fair test – being a compulsory component of the *Australian Curriculum: Science* in upper primary and junior secondary school.

3.2 Prediction – participants make informed guesses about the expected outcomes of their experiment. These predictions are directly tied to their hypothesis, encouraging them to think critically about the relationships between variables and anticipate potential findings.

Prediction statements share similarities with hypothesis statements, but they are more specific and directly tied to how the independent variable is altered and how the dependent variable is observed or measured.

3.3 Observations and Data Collection – participants actively conduct their experiment, record detailed observations and collect data. This stage has a focus on precision and accuracy in both measurements and documentation.

3.4 Data Interpretation and evidence-based claims – participants analyse the collected data to identify patterns, trends, or anomalies. They compare their findings against the initial hypothesis and predictions, reflecting on the results to make *evidence-based claims*. An evidence-based claim is a conclusion drawn from the data collected during the experiment, supported by measurable evidence.

4. Drawing conclusions: participants synthesise thoughts and ideas from their data analysis to form evidence-based conclusions. They evaluate whether the results support their initial hypothesis, discuss alternative explanations for unexpected outcomes, and reflect on the broader significance of their findings. This phase involves critical thinking through deductive reasoning, helping participants bridge the gap between their artificially controlled experimental results and real-world phenomena.

5. Making evaluations: Participants assess the overall investigation process, considering the validity and reliability of their methods and results. They identify limitations, suggest improvements, and evaluate the impact of their findings within their own relevant context. This is a reflective process (improving metacognitive skills) that builds a deeper understanding of both scientific concepts and the overall investigative process – thereby addressing scientific literacy.

The Role of the Facilitator in Experimental Investigations: The facilitator plays a crucial role in experimental investigations, serving as both a co-learner and a co-investigator. This shifts the traditional didactic, teacher-led, approach to an approach that positions the facilitator as a partner in exploration rather than as an authority figure. Modelling the value of asking questions, reflecting on evidence, and actively designing and conducting experiments, and seeking solutions together, encourages participants to see the investigation as a collaborative effort, reducing the fear of failure (Duschl & Bybee, 2014).

This hands-on involvement helps participants navigate complex aspects of the scientific method while encouraging them to take ownership of their learning. Vygotsky's theory of the Zone of Proximal Development (Vygotsky, 1978) encourages facilitators to scaffold learning by providing just enough support to help participants achieve tasks they might not accomplish independently, such as making connections between their observations/conclusions and broader scientific principles. This requires facilitators to balance providing guidance with allowing participants to develop their ideas, leading to both independence and critical thinking, (Manz, 2015).

Perhaps the most significant aspect of facilitators acting as co-learners and co-investigators is the capacity to create safe and inclusive learning environments. By openly engaging in the process of inquiry, facilitators normalise uncertainty and mistakes as integral (and normal) aspects of scientific exploration (Chin & Brown, 2000) and encourages participants to take intellectual risks.

Summary of Benefits of Hands-on Experiential Learning: Adopting hands-on experiential approaches in community science engagement connects participants directly with real-world phenomena, facilitating deep understanding of both scientific concepts and processes. By allowing participants to generate their own questions, hypotheses, and design their own investigations, these approaches not only enhance motivation and engagement but also develop critical thinking, problem-solving, and scientific literacy.

The facilitator's role as a co-learner and co-investigator is vital, striking a balance between guidance and autonomy, and creating a safe environment for curiosity, collaboration, and exploration. When carefully implemented, these strategies not only meet learning goals but also inspire ongoing passion for inquiry and discovery. Ultimately, they help prepare participants to understand and potentially contribute to a world increasingly shaped by scientific and technological advancements.

5.2.3 Case study: *Discover the Microbes Within!*

Discover the Microbes Within! The *Wolbachia* Project, is an innovative science education initiative that immerses students in hands-on experiential research exploring microbial symbiosis and biotechnology (Lemon et al., 2020). Established over 15 years ago, this program integrates biodiversity, bioinformatics, and biotechnology into classroom learning, enabling students to investigate the prevalence of *Wolbachia*, a bacterium found in many arthropods (insects, spiders, scorpions, etc) and has been applied to eliminate mosquito-borne diseases such as dengue from far North Queensland, as well as controlling dengue and Zika in South America and South East Asia. The project combines cutting-edge lab techniques like DNA extraction, PCR, gel electrophoresis, and DNA sequencing with fieldwork, where students collect and identify local arthropods to analyse *Wolbachia* distribution (Bordenstein et al., 2010). These findings are published in a global database, fostering collaboration and contributing to scientific knowledge.

Central to the program's success are the embedded experiential learning activities by applying well established scientific techniques used in research labs around the world. Students begin by collecting insects from their local communities and then, either in their schools or with partner universities, extract DNA and apply genetic techniques including DNA sequencing. Students then analyse their data using computational tools to taxonomically identify the insect collected, determine if that insect was infected by the *Wolbachia* bacterial symbiont, and even determining what strain of *Wolbachia*. Students learn critical molecular biology and bioinformatics skills typically reserved for advanced academic settings. The program encourages local, national and international collaboration by connecting classrooms across countries for data sharing and comparative analysis. For example, each year students and teachers apply for research-travel fellowships to attend a two-day conference at the organising institution, to share their research findings with other students and researchers.

Please follow this link for further details on this project: https://wolbachiaproject.org/

5.3 Engage Relatable Scientists

Involving scientists in community engagement programs plays a key role in enhancing public awareness, understanding, and appreciation of science. By connecting with their communities in a relatable and engaging manner, scientists can demystify complex scientific ideas, make science more accessible and build trust in scientists, scientific knowledge, and scientific institutions. Their participation can also reduce perceptions of elitism and contribute to community-specific challenges with locally relevant expertise. Importantly, relatable scientists serve as role models to inspire the next generation of STEM professionals.

5.3.1 Why engage relatable scientists?

One of the key barriers to effective science engagement by the public is the perception that science is inaccessible or elitist. Many members of the public feel that scientific knowledge is the domain of highly educated professionals situated in ivory towers, distant from the everyday experiences of the public. This perception can be a significant obstacle to community engagement, particularly among groups with lower levels of formal education or those who have historically been under-represented or under-exposed to quality science engagement programs.

THE RATIONALE FOR ENGAGING SCIENTISTS: Scientists bring expertise, unique perspectives, and credibility to community engagement programs. Their active participation provides a level of authenticity that enhances public trust in science and its institutions (Besley, Dudo, Yuan, et al., 2018; Dudo & Besley, 2016). With a deep conceptual understanding, and field-specific knowledge, scientists have the capacity to convey complex scientific concepts accurately and understandably (Weingart et al., 2021). Their familiarity with local contexts also allows them to address community-specific challenges, ensuring that solutions are relevant and impactful (Bonney, Ballard, et al., 2009).

Scientists also serve as inspirational role models in community science programs, influencing career pathways in STEM, particularly for young people (Archer et al., 2020; Ker et al., 2013). This is especially the case when (Gladstone & Cimpian, 2021):

- Scientists are portrayed as competent and successful
- Scientists are portrayed as meaningfully similar to the target audience
- Participants are exposed to scientists from traditionally under-represented groups
- The success of scientists is conveyed as being attainable for participants.

THE RATIONALE FOR ENGAGING 'RELATABLE' SCIENTISTS: While scientists can play a significant role in shaping community awareness and appreciation of science, and can serve as inspirational role models, they often have a PR problem related to public perception and effective communication.

"If They Like You, They Learn From You" – this is the title of an article (Anderson et al., 2013) describing the role that trust and viewer perceptions have on the effectiveness of delivering a science education program by popular TV presenters. The study showed that audiences were more likely to accept and be

positively influenced by presenters when they have a favourable opinion of them. While this paper was deliberately sampled from the literature, there exists significant evidence to support this somewhat intuitive claim.

Fiske and Dupree (Fiske & Dupree, 2014) discuss how scientists are often perceived as "competent but cold", being seen as highly knowledgeable but lacking in warmth and approachability. This stereotype can create a sense of distance between scientists and the public, making it difficult for community members to relate to experts or feel comfortable engaging in community programs.

However, when scientists present themselves and their work in a clear, engaging, and empathetic manner that resonates with the audience's experiences and values, they engender a sense of connection, trust and credibility with their local communities – ultimately leading to more effective engagement (Wynne, 2006).

Ironically, scientists themselves value the traits of 'trustworthiness' and 'credibility' highest when engaging with the public, which serves to drive intrinsic motivation for successful participation in community programs – for those scientists who choose to engage (Besley et al., 2015). Gaining public trust and credibility, in turn, leads to greater understanding, and greater acceptance, of the scientific ideas and processes being addressed.

Public trust and appreciation of science is not based on the nature or accuracy of the information provided by scientists, but on the perceived intentions, openness, and empathy of the scientists themselves. Studies (Besley et al., 2015; Dudo & Besley, 2016) show that public trust and positive beliefs about science and scientists, correlate with how relatable scientists are perceived to be, and to what extent they are "likeable, engaging, and willing to listen" to public concerns. When scientists engage in a relatable manner – for example, by sharing personal stories, showing vulnerability, or demonstrating a genuine interest in the concerns of the community – they build stronger relationships with participants, resulting in greater trust in both the science and the scientists (Bauer et al., 2007). Myers et al. (Myers et al., 2012) show that well designed community engagement programs that integrate interpersonal, interactive experiences with new scientific knowledge are more effective at shaping public attitudes and beliefs about science than programs that focus on scientists simply sharing information.

Storksdieck et al. (Storksdieck et al., 2016) identified three essential components of community engagement by scientists:

1. Scientists consider the needs, desires, affordances and abilities of their audiences.
2. Engagement is structured as bi-directional dialogue between scientists and audiences.
3. Scientists and their audiences feel empowered to be part of a mutual learning experience that influences.

Facilitating scientific understanding: The way scientists communicate also significantly affects how well scientific concepts are understood by public audiences. Many studies, e.g. (Nisbet, 2008; Scheufele & Krause, 2019), highlight the importance of scientists 'framing' community engagement in a way that resonates with the audience's values, beliefs, and experiences. For example, a climate scientist engaging rural communities might discuss the impacts of climate change on crops, using language and examples that are directly relevant to the farmers' everyday experiences.

Framing can also help scientists to shape preferences for science-informed government policies, influence personal or political behaviour, and bridge polarisation within the community by uniting diverse groups around shared understandings and values (Nisbet, 2008).

5.3.2 Implementation – motivations, barriers and solutions for engaging relatable scientists

Understanding the motivations of scientists and identifying barriers for engagement in community science programs is crucial in terms of securing their active participation. By recognising challenges such as time constraints, institutional support, and perceived value, while also leveraging motivations like public impact, professional development, and funding opportunities, programs can be designed to better support and sustain involvement by scientists.

Motivations for Scientists' Participation in Community Engagement Programs: Recent literature offers a comprehensive understanding of why scientists engage in community science programs (Barthel, 2020; Besley, Dudo, & Yuan, 2018; Copple et al., 2020; Yuan et al., 2017). Individually, scientists are motivated by both academic and social factors. Academic motivations include correcting misconceptions or defending scientific concepts, sharing research outcomes, generating public excitement about specific scientific topics (Dudo & Besley, 2016), addressing criticism of science (Besley & Tanner, 2011), and contributing expertise to inform policy development (Funk et al., 2015; Rose et al., 2019; Scheufele, 2014).

Social motivations include enhancing their own self-efficacy, shaping their professional identity (Christopherson et al., 2018; Risien & Storksdieck, 2018), inspiring future scientists, promoting scientific literacy (Besley & Nisbet, 2011), and promoting diversity in STEM, particularly among underrepresented groups (Allen-Ramdial & Campbell, 2014). Younger scientists, in particular, see community engagement as a way to improve communication skills and teaching effectiveness (Andrews et al., 2005). Besley et al. (Besley, Dudo, Yuan, et al., 2018) also found that scientists who believed their outreach efforts could create tangible real-world impacts were more inclined to participate in community engagement. They also found that scientists with greater confidence in their outreach skills were more likely to participate in face-to-face science community engagement.

Barriers for Scientists' Participation in Community Engagement Programs: The most commonly cited barriers for scientist engagement with community science programs are time, funding, knowledge, training and institutional support. For most scientists, lack of time is the greatest barrier (Andrews et al., 2005; Woitowich et al., 2021). Compounding time constraints is a lack of knowledge and understanding about what outreach opportunities are available and how best to engage, ultimately forcing individuals to expend considerable time and effort to create or locate appropriate opportunities (Andrews et al., 2005; Mathews et al., 2005). Difficulties around logistics and coordination of events are another deterrent (Abes et al., 2002; Holland, 2019).

Others feel they lack the necessary knowledge and communication skills to effectively participate in outreach efforts (Mathews et al., 2005; Shanley & López, 2009); they further feel that their efforts could therefore do more harm than good, resulting in negative public perception of science if they participate (Poliakoff & Webb, 2007). Finally, lack of institutional support and lack of recognition and rewards, especially in the tenure process, are also barriers to participation (Holland, 2019).

Practical advice for Engaging Relatable Scientists: The findings outlined above regarding scientist motivations and barriers to engagement require community science engagement programs to take an active role in facilitating scientist participation. Areas where scientists can be assisted to overcome barriers and support their existing motivations include institutional support, funding, logistics and coordination, and training of scientists. In addition, science engagement programs can assist scientists to develop their own longer-term goals and objectives for their outreach efforts, hopefully facilitating meaningful contributions to community science initiatives well into the future.

Institutional support: If scientists receive strong institutional support from their own organisation, many barriers (such as time constraints, funding, and training) become manageable. Impacting the institutional priorities of other organisations involves demonstrating the value that community engagement brings to both the institution and the broader community. Working directly with scientists within an organisation to advocate for engagement can help establish partnerships and collaborations that benefit all stakeholders.

Adopting the principles of *Collaborative Advantage* (Chapter 4.5) can highlight the advantages of collaboration, articulating how community engagement aligns with the strategic priorities of the institution. Engagement programs should demonstrate how participation contributes to institutional goals such as public visibility, student recruitment, funding opportunities, and overall impact.

Funding and resourcing: Once institutional support has been secured, accessing funding and leveraging existing (combined) resources becomes more feasible. Collaborative funding applications (where both the institution and the engagement program contribute) can be a successful strategy. Many funding agencies, including governmental research bodies and private foundations, prioritise projects with strong community links, including interdisciplinary partnerships.

In addition to securing direct funding, engagement programs should explore opportunities to repurpose existing resources. For example, government departments, and university faculties and outreach programs, often have personnel, infrastructure and materials that can be shared. By integrating with these existing resources, community science engagement programs can reduce financial barriers and ensure that scientists from these organisations have the necessary support to participate effectively.

Logistics and coordination: Arguably, the most tangible way community science engagement programs can support scientists is by handling logistics and coordination. Scientists often cite event management, scheduling, and administrative work as significant deterrents to community engagement. Programs should take on these responsibilities, ensuring that scientists can focus on delivering content and engaging participants, rather than managing operational details.

This support includes arranging venues, managing registrations, coordinating with schools or community groups, handling transportation logistics, providing materials for events and organising morning tea and lunch breaks. Mature engagement programs typically have standardised event formats and templates to simplify logistical planning, allowing scientists to integrate outreach activities into their schedules with minimal effort.

Training: Many established community engagement programs have STEM professionals with expertise in science communication and science education, which can be leveraged to train scientists in effective community engagement. These professionals can provide guidance on aspects such as curriculum alignment, pedagogical strategies, and strategies for communicating complex scientific concepts to diverse audiences.

When in-house training is unavailable, scientists can be directed to existing training opportunities. Many universities offer professional development courses in science communication, while organisations like the *Alan Alda Centre for Communicating Science*, the *Portal to Public Network*, and online platforms such as Coursera and edX, provide training modules tailored to scientists. These programs focus on developing engagement tactics, enhancing public speaking and media communication skills, and developing confidence in diverse outreach settings. **Appendix I** provides a list of opportunities and resources to assist scientists engaging with the public.

Assist scientists to understand their rationale for community engagement: While it is important for scientists to be engaging and relatable, it is also important for them to have clarity of purpose and understand why they wish to engage with the broader community. For many, particularly those new to community engagement, their strategic objectives may be unclear.

Whatever their purpose, and whether it is initially known or unknown, coordinators of science engagement programs should assist scientists to articulate their long-term engagement goals and shorter-term objectives. Doing this will develop a stronger, longer-term, commitment to engagement initiatives.

Besley et al. (Besley, Dudo, & Yuan, 2018; Dudo & Besley, 2016) articulate a range of objectives for why scientist choose to, or wish to, engage with the broader community. They articulate two baseline or default objectives as being common for many scientists and commonly addressed in the literature:

- Ensuring people are informed about scientific issues.
- Getting people interested or excited about science.

They also articulate six other objectives related to aspects of trust and the importance of scientific identity:

- Demonstrating the scientific community's expertise.
- Hearing what others think about scientific issues.
- Demonstrating that the scientific community cares about society's well-being.
- Demonstrating the scientific community's openness and transparency.
- Demonstrating that scientists are part of their local community and share community values.
- Framing research outcomes and implications that resonates with their values.

To assist scientists to identify their own objectives, Lewenstein et al. (Lewenstein & Baram-Tsabari, 2022) provides an excellent rubric for evaluating scientist engagement with community outreach and communication.

5.4 Influence the Influencers

Community science engagement programs can play a vital role in inspiring young people to pursue STEM studies and careers. However, students often make these choices based on the advice and perceptions of key influencers such as parents, teachers, friends, career advisors, industry mentors and media influences. By targeting these influencers, community science programs can significantly increase youth participation (especially in underrepresented communities) and long-term interest in STEM studies and careers.

5.4.1 W*ho are the influencers and why engage them?*

A series of recent STEM Influencer reports commissioned by the Australian Department of Industry Science Energy and Resources (YouthInsight, 2022(a), 2022(b), 2023), offer key insights into the factors that influence young Australians' choices regarding STEM studies and STEM careers. The reports highlight the key influencers in students' subject and career choices, as well as the personal motivations driving their engagement with STEM.

When it comes to influencing STEM subject choices in post-compulsory secondary education, parents have by far the greatest impact, with 46% of students citing them as key decision-makers. Parental experiences, beliefs and occupations tend to be the inspiration for the future aspirations of Australian youth.

Beyond family, there is a mix of wider influences with teachers (24%) and friends (22%) being the other key influencers, while less significant influencers include extended family members, successful business figures, career advisors, and well-known scientists. Interestingly, celebrities also play a minor role, reflecting the growing influence of media (and social media) figures in shaping student perceptions.

Beyond external influencers, students' personal motivations also play a crucial role in their decision to pursue STEM studies and ultimately STEM careers. The most cited reason is personal interest in STEM (59%), followed closely by confidence in their own STEM skills and abilities (55%). Potential future earnings (27%) and an ambition to change the world (19%) are also key drivers. Other cited personal motivators include previous STEM-based work experiences, the wish to boost their Australian Tertiary Admission Rank (ATAR) score (13%) and fulfilling a childhood dream (13%). Notably, 10% cite social media, particularly YouTube, as a motivating factor, underscoring the growing role of digital platforms in shaping career aspirations.

A few key insights from the findings in the YouthInsights reports (YouthInsight, 2022(a), 2022(b), 2023) include:

1) Gender Differences:

a) With regard to parental influence, fathers were significantly more likely to hold higher education qualifications than mothers. This disparity was even more pronounced in STEM fields; fathers were also far more likely to be interested in STEM (YouthInsight, 2022(a)).
b) While most parents perceive science as a gender-neutral subject, mothers are more likely than fathers to believe that boys have greater confidence in STEM than girls. The data also indicate that mothers, more than fathers, tend to favour boys over girls in their perceptions of STEM aptitude.
c) Across a range of school subject areas, a sizeable proportion of educators (35-45%) note gendered differences in students, citing boys as more confident in engineering, sport, technology, mathematics and science, and girls more confident in social science, arts and English (YouthInsight, 2022(b)).

Given that parents and teachers are the most influential groups in shaping young people's educational and career choices, this gender imbalance in STEM qualifications and perceptions of aptitude (by parents) and confidence (by parents and teachers) underscores a key theme of the influencer studies; i.e., how foundational biases in STEM representation and STEM influence may contribute to broader gender patterns in engagement and career aspirations (YouthInsight, 2022(a)).

2) Underrepresented Groups:

a) Parental qualifications in STEM
    i. Parents in metropolitan areas (38%) are more likely to have STEM qualifications than those in regional or remote areas (19%).
    ii. Higher SES parents (35%) are more likely to hold STEM qualifications compared to lower SES parents (28%).
    iii. STEM qualifications are more common among parents from CALD (42%) than non-CALD backgrounds (30%).
b) Parental Expectations
    i. Parents from high SES areas are more likely to expect their children to pursue higher education than those from low SES areas (72% vs 52%).
    ii. Similarly, parents from CALD backgrounds have higher expectations for their children's higher education compared to non-CALD parents (79% vs 60%).

c) Parental Perceptions and Understanding of STEM
    i. Only 15% of parents could not identify any broader life skills linked to STEM education. These parents were more likely to come from regional or remote areas, lower SES backgrounds, and non-CALD communities.
    ii. Parents with a CALD background and parents from higher SES areas hold higher perceptions of the importance of STEM compared to non-CALD parents and those from those from lower SES and rural/remote communities.

3) Career Advice:

a) In addition to specialised mentors and career advisors, most secondary school teachers provide some level of career advice to students throughout the school year.
b) However, the advice on STEM career options to girls and boys are not presented in the same way, with boys more frequently encouraged to pursue careers in engineering and trades, whereas girls are more often steered toward research roles (YouthInsight, 2022(b)).
c) When advising students on STEM careers, advisors highlight local STEM employers, the wide range of job opportunities requiring STEM skills, and the financial support (e.g. scholarships) and specific career pathways available, particularly designed to encourage greater female participation in STEM (YouthInsight, 2022(b)).

4) Perceptions, Attitudes and Aspirations of Young Australians (YouthInsight, 2023):

a) Young people with parents educated in STEM or whose parents work STEM-related jobs have a better understanding of STEM and pursue post-compulsory STEM studies compared to those without this parental influence.
b) Clear familial and cultural differences are apparent in STEM aspirations, with young people from CALD backgrounds, and those born overseas, more likely to pursue STEM studies and careers than their Australian-born or non-CALD peers.
c) 39% of Year 11-12 students intend to study STEM at tertiary level, driven largely by boys (47%) compared to 31% for girls.
d) Key opportunities remain to boost interest in STEM studies by raising awareness of STEM-related career pathways. The data shows that even *basic career messaging* increased interest in STEM with 36% of students being more interested in STEM education after a simple explanation of STEM career opportunities.

Overall, key elements common in career choices for Australian youth that are identified in the above YouthInsight reports include:

- Being content and fulfilled
- Being financially secure
- Finding a career they love in a field that fits their passions.

THE INTERNATIONAL LANDSCAPE: The picture painted above for the Australian landscape is mirrored internationally. Research studies consistently highlight the impact of familial support (mainly parents), school influence (mainly teachers), and student self-efficacy in study as the main predictors of STEM study and career choices (Mau & Li, 2018; Schuster & Martiny, 2017; Van Tuijl & van der Molen, 2016).

Gender and race are also crucial predictors, with female and minority students often facing barriers such as lack of confidence, discrimination, and financial pressures, which can hinder their interest in STEM (Raque-Bogdan et al., 2013; Riegle-Crumb et al., 2011). These challenges contribute to the underrepresentation of these groups in STEM careers, despite their potential.

In a comprehensive review of 160 studies focussing on aspirations in STEM, Van Tuijl et al. (Van Tuijl & van der Molen, 2016) concluded that career decisions are shaped well before adolescence and that early interventions supporting parental and teacher understandings about STEM opportunities and reducing ingrained stereotyping were the keys to increasing STEM engagement.

THE ASPIRES PROJECTS: Similar outcomes also arise from the ASPIRES Projects (Archer et al., 2023; Archer et al., 2020; Ker et al., 2013) – the most comprehensive series of longitudinal studies ever undertaken regarding STEM study and career aspirations of young people. Overall outcomes show a complex interplay of influencer impact (family, school, gender, SES status, and self-perceptions) all significantly influence students' STEM aspirations. The study highlighted the need for more inclusive approaches to STEM education, particularly those that build science capital in marginalised communities. This includes providing appropriate role models for students in these communities and addressing biases within schools and the broader community. Furthermore, increasing early exposure to formal and informal STEM learning opportunities in diverse and supportive contexts can help break down barriers that discourage students (particularly girls and minority groups) from pursuing STEM careers.

The overriding recommendation from the ASPIRES projects was *"change the system not the people"*, in strong accordance with the Australian government's *Pathway to Diversity in STEM* report (Bergman et al., 2023) – *"people underrepresented in STEM too often carry the weight of advocating for change … these individuals should not have to change to belong and thrive"*.

THE IMPORTANCE OF PARENTS: The importance of parents as influencers is universally accepted. When parents actively participate in their children's STEM learning, it enhances academic confidence, improves motivation and curiosity, and strengthens family bonds (Anderson & Minke, 2007; Banerjee et al., 2011; Ing, 2014). Parents do not need to be STEM experts to make a difference – simply showing interest, asking questions, and participating in informal STEM learning activities together has shown profound impacts (Marotto & Milner-Bolotin, 2018; Milner-Bolotin & Marotto, 2018).

However, many parents, particularly those from underrepresented backgrounds, often feel unsure about how best to support their children in STEM (Milner-Bolotin & Marotto, 2018). Beyond academic benefits, many parents also see STEM education as a gateway to future economic success (Ayalon & Yuchtman-Yaar, 1989; Marotto & Milner-Bolotin, 2018).

A recent paper detailing a 4-year longitudinal study of STEM aspirations of over 6000 NSW students, and their parents, concluded by noting *"the need for institutions to develop interventions that successfully leverage the influence of parents"* (Lloyd et al., 2018).

5.4.2 How to Influence the Influencers

The findings above suggest that community science programs can play a key role in shaping youth decisions about STEM futures by directly targeting both external influencers (parents, teachers, peers, and media figures) and personal motivations (interest, confidence, career prospects, and societal impact). In addition, studies show that direct career guidance via vocational training can have a profound effect on STEM aspirations, even at very young ages.

INFLUENCING PARENTS: Since parents are the most important influencers in shaping their children's STEM interests, community science programs should prioritise family involvement. Initiatives such as science festivals, maker spaces, and informal learning spaces (such as museums and science centres) create opportunities for parents and children to engage in hands-on learning together, reinforcing the importance of STEM and STEM education. By actively participating in these experiences with their children, parents send a powerful message to their children that STEM is important, relevant, and engaging.

Moreover, when parents engage with STEM firsthand through joint experiences with their children, the value they place on STEM with respect to their children's future is enhanced and they are better able to articulate reasons to encourage their children to engage with STEM (Marotto & Milner-Bolotin, 2018).

Resources and training for parents – promoting the 'utility value' of STEM: Many parents lack the necessary knowledge and support to influence their children to pursue STEM studies and careers (Hill & Tyson, 2009; Hyde et al., 2006). Providing simple, accessible resources and training (particularly for parents from underrepresented backgrounds) can equip parents to nurture their child's STEM aspirations.

Studies show that it is possible to influence the perceived value of STEM studies with simple interventions that provide students and parents with basic information about the 'utility value' of a topic or school subject (Harackiewicz et al., 2012; Shechter et al., 2011; Slotkin et al., 2024). Harackiewicz et al. (Harackiewicz et al., 2012) describe a simple three-part intervention consisting of a website and two brochures mailed to parents, all highlighting the usefulness of post-compulsory STEM studies at school. The resources were not focussed on science concepts or ideas, but rather on the benefits of STEM subjects including the development of 21st century enterprise skills, e.g. analytical problem-solving skills, critical thinking skills, evidence-based reasoning, creativity, digital and numerical literacies, and teambuilding skills. This simple intervention resulted in students of the participating parents taking, on average, nearly six-months more science and mathematics in the last two years of high school compared to students whose parents did not participate.

A UK study (Hyde et al., 2017) examining role of mothers' communication in promoting motivation for maths and science positively impacted both the interest and utility value for Year 9 students, as well as subsequent uptake of these subjects in senior school.

In essence, therefore, the research suggests that it may be easier for parents to demonstrate the utility value of STEM studies rather than assisting their children to find these subjects interesting. For example, if parents cannot convince their child that science is fun ('intrinsic value') or that he or she is good at it, they can discuss how useful ('utility value') the knowledge and skills gained by studying STEM subjects can be for gaining university entrance or for careers in any field, not just STEM related careers.

Influencing parents – the role that schools and community science programs can play: The intervention described above by Harackiewicz et al. (Harackiewicz et al., 2012) was an example of schools outreaching to parents to improve STEM aspirations for their children. A USA study of 11,000 parents of high school seniors (Simon, 2004) showed the importance of outreach activities by schools (to parents), and the influence it has on student success and aspirations. The study showed that parents who received more outreach by their teenagers' high schools reported:

- more parent-teenager discussions about post-secondary educational planning and employment
- higher attendance at university-planning workshops
- greater frequency of attending school activities with their teenagers, and
- more work with their teenagers on homework.

Importantly, these results were achieved regardless of teenagers' socioeconomic status, gender, family structure, race/ethnicity, and academic achievement.

This study suggests that schools and community science engagement programs have the ready capacity to influence the most important influencers of student study and career aspirations (i.e. parents) – simply by reaching out to them. And this effect will be felt by children irrespective of their familial background.

Mothers of Daughters: Special attention should also be given to engaging mothers of daughters, as research suggests they may unknowingly exhibit biases that favour boys in STEM-related confidence and ability (YouthInsight, 2022(a)) – thereby unconsciously steering their daughters away from STEM opportunities. Raising awareness among parents, especially mothers, about gendered stereotypes *"that may prevent them from encouraging their daughters as much as they encourage their sons is thus an important consideration"* (Lloyd et al., 2018).

Research also shows that of the multiple influences on children's mathematics achievement, the predictor with the largest effect is mother's education, followed by home learning environment, quality of primary school, and family's socioeconomic status (Melhuish, 2011; Melhuish et al., 2008). An Australian study has also shown that upskilling mothers with basic IT skills led to participants questioning their own (negative) pre-conceived ideas about IT careers for women (Stockdale & Keane, 2016).

INFLUENCING TEACHERS: 24% of Australian students identify teachers as key influencers in their study and career choices (YouthInsight, 2022(a)), serving as role models, providing career advice and stimulating interest in science through their teaching (Krapp & Prenzel, 2011; OECD, 2008). However, research highlights that many teachers, particularly female primary school teachers, lack confidence in teaching STEM, leading to rigid instructional approaches that hinder exploration, pleasure, interest and deep learning (Appleton & Kindt, 1999; van Aalderen-Smeets et al., 2012). The beliefs, attitudes and gendered stereotyping found in these teachers play a crucial role in determining the attitudes of students towards science, impacting the future STEM opportunities of their students (Archer et al., 2012a; Li, 1999).

Addressing these issues through targeted professional development, explicitly addressing content knowledge, pedagogical approaches, and teacher beliefs and attitudes, is crucial for promoting sustained interest in STEM for school aged children (Osborne et al., 2003).

Engaging Teachers in Professional Development: School educators are time poor; they are also under pressure to produce student learning outcomes against a tightly packed *Australian Curriculum* with little room for extraneous content or contact. Engaging teachers and schools as part of community science programs therefore requires a focus on enhancing student learning outcomes either via direct contact with students or through professional learning opportunities for teachers.

The purpose of any teacher professional learning program should involve impacting teacher practices and/or understandings, with the ultimate aim of improving outcomes for students. In terms of influencing teachers with a view to them subsequently influencing student aspirations in STEM, community engagement programs could focus on:

- Supporting teacher content knowledge and pedagogical skills – professional learning helps teachers stay updated on the latest concepts, discoveries, and best teaching practices
    - many educators, especially at the primary level, have a limited STEM background, so ongoing professional development helps them develop both content expertise and instructional strategies for effectively engaging students.
- Changing practice – providing opportunities for teachers to be better equipped to deliver STEM lessons that have proven capacity to improve student scientific literacy
    - for example, through the inquiry-based and hands-on experiential learning approaches outlined in Chapters 5.1 and 5.2.
- Encouraging external collaborations and professional networking by providing opportunities for teachers to engage with practicing scientists and other STEM professionals
    - these individuals act as powerful role models for both teachers and their students.

- Highlighting the value of STEM studies and STEM careers
    - and connecting these ideas to parental engagement in ways described above.
- Supporting teacher understanding of science capital and how, and to what extent, teachers take a science capital approach to their teaching (Godfrey Lopez, 2024)
    - this includes taking approaches that go beyond developing scientific literacy (what students know) to include other components of science capital that impact 'what students think', 'what students do' and 'who students know' in STEM.

Key generic tips for facilitating teacher professional learning opportunities, include:

- Connect with teachers and school leaders
    - ascertain what professional learning needs are required across the sector, across the school or for individual teachers, and where appropriate co-design professional learning experiences with education leaders.
- Make it practical and hands-on
    - teachers benefit most from professional development that provides tangible, classroom-ready strategies by adopting inquiry-based, hands-on experiences that can be directly replicated with students.
- Connect STEM to real-world applications
    - educators are more likely to embrace STEM when they see its real-world relevance, so professional learning should highlight practical STEM applications and career connections through, for example, industry speakers or workplace visits.
- Provide ongoing support and collaboration
    - one-time professional learning events rarely create lasting change, so ongoing mentorship, development of professional "communities of practice", and school-industry collaborations ensure teachers stay supported.
- Incentivise participation and recognise effort
    - make professional learning rewarding, by offering certifications and/or awards to encourage sustained engagement in professional learning activities.

In addition, literature review studies (Driel, 2014) show the following elements are important strategies aimed at developing successful professional learning opportunities for teachers:

- an explicit focus on teachers' initial knowledge, beliefs and concerns
- opportunities for teachers to experiment in their own practice
- collegial co-operation or exchange among teachers, and
- sufficient time for changes to occur.

Finally, two more reasons for maintaining ongoing professional learning relationships with teachers:

- "*Outreach connected teachers act as gatekeepers by negotiating access into their colleagues classrooms"* – and therefore access to their students (Martins Gomes & McCauley, 2021).
- *"Teachers possess proximity, permanence, and a strong grasp of pedagogical theory, and as such are a powerful presence to influence change"* (McCauley & Davison, 2024).

PEER INFLUENCES: Given that 22% of Australian students are influenced by their peers (YouthInsight, 2023), science engagement programs should create collaborative, social experiences that encourage group-youth participation.

Events such as STEM competitions, coding hackathons, and robotics challenges allow students to interact with like-minded peers. Mentorship programs and student-led STEM outreach (Wood & Wood) can also help with peer influences normalising STEM as an exciting and achievable path.

Self-Driven Influences: For students motivated by personal interest (59%) and confidence in their own abilities (55%) (YouthInsight, 2023), hands-on science programs such as afterschool science clubs, citizen science projects, research internships, and STEM camps provide critical exposure to real-world problem-solving, reinforcing existing knowledge, skills and curiosity.

Students who prioritise future career prospects (27%) and work experience (16%) (YouthInsight, 2023), will find value in direct interactions with STEM professionals through industry talks, workplace tours, 'work experience' and internships.

For those driven by a desire to "change the world" (19%) (YouthInsight, 2023), STEM engagement programs should highlight the societal impact of STEM. Initiatives focused on climate science, biomedical research, space exploration, and sustainable energy can demonstrate how STEM careers contribute to solving global challenges, inspiring students who are motivated by purpose rather than financial gain.

Advice on Career Guidance Initiatives: A comprehensive review of study choice and career development in STEM fields is provided by Van Tuijl et al. (Van Tuijl & van der Molen, 2016), examining psychological, sociological, educational, and vocational perspectives. Two key findings from this study provide practical insights of relevance with regard to career guidance:

1) STEM career decision development starts early: *"Vocational development begins much earlier in the life span than generally assumed, and what children learn about work and occupations has a profound effect on the choices they make as adolescents and young adults, and ultimately, on their occupational careers"* (Van Tuijl & van der Molen, 2016).

While formal career guidance and counselling starts in school, it is generally focused on middle school students (ages 13-15), which, from a developmental approach, is too late. Career choices are shaped in primary and middle school years (ages 8-15) through early personal and familial experiences, exposure to stereotypes, and studying science and other subjects at school. Lack of specific vocational advice results in many young children prematurely ruling out STEM careers due to misconceptions about difficulty and (especially) suitability.

2) Key influencers lack awareness and understanding: *"In general, students, teachers as well as parents and school counsellors seem ill-informed with regard to the opportunities and chances that further education in the STEM-field may offer"* (Van Tuijl & van der Molen, 2016). Hence the need for professional development of teachers and the provision of resources for parents (described above) for raising awareness and positively affecting student perceptions and aspirations in STEM.

Detailed provision of study and career advice for guiding the future aspirations of young students is generally not an overt focus for most community science programs. It seems therefore that an opportunity exists for community programs to take a more active role in STEM career guidance by integrating structured career exploration activities into their programs. Approaches that could be practically implemented include:

Starting young – by introducing STEM career discussions to primary school students through storytelling, hands-on activities, and relevant educational resources. For example, two early reader Australian resources *('Suzie the Scientist'* and '*Millie the Mathematician*') connect K-3 students and their parents with engaging, curriculum aligned, STEM content using uniquely Australian contexts.

The content is facilitated by two relatable female role models (*Suzie* and *Millie*) **–** demonstrating, from the earliest of ages, that STEM and STEM studies are appropriate pursuits for all (see **Appendix J**).

Showcase real-world applications of STEM – students often disengage with STEM because they fail to see its relevance to everyday life and future careers (OECD, 2008). Linking outreach activities to local issues or global challenges (such as climate change, renewable energies, space exploration) will increase the chance of sparking an interest in STEM.

Challenge stereotypes and gender bias in STEM – children, particularly those from underrepresented backgrounds, need visible STEM role models to inspire them and counter stereotypes (Archer et al., 2012). Challenge gender norms by showcasing female and minority STEM leaders in outreach activities and career talks.

Engage key influencers in STEM career awareness – including parents and teachers, providing STEM-related career resources and highlighting the diverse pathways and multiple entry points into STEM studies and STEM careers.

Use age-appropriate career-exploration tools – see **Appendix J** for online STEM career platforms.

By addressing the knowledge gaps among key influencers and promoting early career awareness in students, community science engagement programs can ensure that more young people consider and pursue STEM pathways.

5.5 Utilise Informal Learning Places and Programs

This principle recognises the significant role that informal learning environments play in promoting engagement and learning in science beyond traditional school-based classroom settings. It also recognises the broad base of STEM-learning assets that already exist in community civic amenities such as museums, science centres and botanic gardens. Community science engagement programs, whether well-established or newly developing, should therefore leverage these existing assets to enhance the impact of their own programs and activities.

5.5.1 Why engage with informal learning places and programs

Most people spend only a small portion of their lives in school, making informal, out-of-school, learning experiences (such as visiting museums or watching nature documentaries) especially significant in shaping scientific understanding over time (Falk & Dierking, 2010). The collective science learning that occurs beyond formal education is known as *informal science learning* (ISL) and encompasses a diverse range of experiences categorised into three main types (Bell et al., 2009):

- **everyday environments –** watching TV, reading news articles etc.
- **designed learning places –** museums, science centres, planetariums, aquariums, botanic gardens etc.
- **structured programs –** science clubs, citizen science initiatives, university outreach programs, science festivals, community-led environmental organisations.

Integrating informal science learning environments into community science engagement initiatives offers several unique benefits for engagement and scientific exploration not afforded elsewhere (Denson et al., 2015; DeWitt & Archer, 2017). In a seminal USA National Research Council report, Bell et al. (Bell et al., 2009) examined the significant role ISL environments play in science learning and promoting interest in science. The study examined how everyday experiences, designed spaces, outreach programs and media-based learning contribute to scientific understanding, identifying six strands of science learning that take place outside of formal classroom settings:

1. Developing interest in science
2. Understanding scientific knowledge
3. Engaging in scientific reasoning
4. Reflecting on the nature of science
5. Using scientific tools and language
6. Identifying oneself as a science learner

These strands not only emphasise scientific knowledge acquisition but also motivation, identity, and social engagement with science. Not surprisingly, therefore, these strands align closely with several aspects of science capital, i.e.: "What you know" (strands 2 and 3); "How you think" (strands 1, 4 and 6); and "What you do" and "Who you know" (strand 5). This alignment, therefore, reinforces the established connection between science capital and active participation in informal science learning programs (Archer et al., 2015; DeWitt & Archer, 2017).

The National Research Council report also highlights how deliberately designed informal learning spaces are more effective in exposing individuals to scientific concepts in engaging, interactive ways that promotes curiosity and deeper learning, compared to more passive modes of learning typical of many science classrooms.

The 95% Solution: Falk and Dierking (Falk & Dierking, 2010) take this notion further, by challenging the traditional assumption that formal education is the primary mechanism for science learning. They argue that most science learning occurs outside of the classroom – through everyday experiences, the media and engagement with informal learning spaces such as museums and science centres. With only 5% of an individual's lifetime spent in formal schooling, they assert that during the other 95% of time informal (free choice) learning plays a crucial role in developing civic scientific literacy, citing (*inter alia*) several studies to support their assertions.

BENEFITS OF INFORMAL LEARNING PLACES AND PROGRAMS: Denson et al. (Denson et al., 2015) identify eight key themes highlighting the benefits of informal learning environments (ILE's) – many of which are unique to ILE's and, when considered together, are only generally experienced within these settings:

- **Informal Mentoring** – participants receive guidance from peers, teachers, and STEM professionals in a supportive learning community
- **Makes Learning Fun** – STEM activities in informal settings engage students through hands-on, interactive experiences, making learning fun
- **Time Management** – participation in ongoing structured programs teaches participants to manage projects, deadlines, and responsibilities
- **Application of Mathematics and Science** – participants in informal learning see the real-world relevance of STEM concepts
- **Feelings of Accomplishment** – completing STEM activities and competitions in informal environments gives participants a sense of achievement and motivation to continue learning
- **Builds Confidence** – success in informal STEM programs increases students' self-efficacy and belief in their abilities
- **Camaraderie** – working in teams develops friendships and a sense of belonging in the STEM community
- **Exposure to New Opportunities** – many participants, especially from disadvantaged backgrounds, gain access to university visits, STEM careers events, and networking opportunities that they would not have otherwise.

Beyond these broad benefits for individuals, the literature identifies several other compelling justifications for why community science engagement programs should collaborate with informal learning environments. These are outlined below.

Access and reach: Informal learning spaces attract large and diverse audiences[5], including those who may not typically engage with science in formal educational formats. The unique aspects of these informal experiences contribute to their effectiveness in engaging a broader audience. Alongside the general benefits listed above, Denson et al. (Denson et al., 2015) also highlight that informal STEM learning environments are critical for promoting diversity and inclusion in STEM. Formal education alone has struggled to attract and retain diverse students in STEM fields, so informal learning environments provide an alternative pathway that combines engagement and persistence in STEM.

Falk et al. (2010) also highlight that visitor patterns to the Los Angeles Science Centre *"are broadly representative of the general population of greater L.A. including individuals from all races and ethnicities, ages, education, and income levels with some of the strongest beliefs of impact expressed by minority and low-income individuals."*

Woods-McConney et al. (Woods-McConney et al., 2013) suggest science engagement outside school is particularly important for Indigenous and underrepresented students, as it provides opportunities to develop science literacy and engagement that formal education often fails to achieve.

There is also evidence that well-designed and implemented informal learning programs, specifically targeting girls, can offer rich and engaging experiences (Denson et al., 2015; McCreedy & Dierking, 2013). These programs have not only had success in the short term, such as increased confidence and participation in STEM among girls (Denson 2015), but also *"cascading long-term influences on women's future choices in education and careers as well as leisure pursuits"* (McCreedy & Dierking, 2013).

While providing opportunities to reach younger diverse audiences, informal learning places also attract large numbers of adult lifelong learners, broadening the impact of community science programs and impacting significantly on broader civic scientific literacy (Falk & Dierking, 2010). Importantly, and in a way that few other settings can achieve, these spaces also encourage cooperative and collaborative learning experiences between parents and children, strengthening intergenerational connections to science and facilitating ongoing conversations and engagement with science at home – a key facet of developing science capital.

However, as noted in Chapter 4.6, other studies (Dawson, 2014; DeWitt et al., 2025) suggest that while informal science learning environments engage large and diverse audiences, many still need to take further steps to address barriers for underrepresented groups to ensure equitable access and participation for all individuals.

Engaging interactive learning: Unlike traditional learning environments, informal science learning spaces are more able to focus on engaging, hands-on, experiential learning. Interactive exhibits, live demonstrations, and immersive experiences help make scientific concepts more engaging and memorable for participants. Designed spaces (such as science centres and museums) also plan exhibition spaces and hands-on activities to align with the principles of how people learn (Gilbert, 2005; John D. Bransford et al., 2000; M. Suzanne Donovan et al., 1999), for example, by demonstrating the same scientific concept at work multiple times using multiple modes of representation. This ensures learning is not just fun and engaging, but effective.

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[5] ABS data show close to 30% of Australians visit a museum each year (28% of adults and 31% of children). Source: https://www.abs.gov.au/statistics/people/people-and-communities/cultural-and-creative-activities/latest-release

Scientific understanding and scientific literacy: Over many years the research literature has identified that informal science experiences significantly contribute to enhancing science learning and scientific literacy across diverse populations (Falk & Dierking, 2010; Falk et al., 2007; Kim & Dopico, 2016; Lucas, 1983; Maarschalk, 1988). Miller (Miller, 1998) identified the importance of informal learning in science as *"second only to college (university) level science courses"* in terms of civic scientific literacy, identifying that individuals continue to acquire and apply scientific knowledge well beyond formal education (Falk & Dierking, 2010).

More recently, a meta-analysis by Xia et al. (Xia et al., 2024) concluded that students who participated in out-of-school STEM learning showed higher understanding, curiosity, and participation in science and technology fields. This was also reinforced by analysis of the 2015 Program for International Student Assessment (PISA) results (Tang & Zhang, 2020), showing that students who engaged in early informal science learning performed better in the 'science competency' category due to improved self-efficacy and interest in science.

Interest, attitudes, and identity: Beyond knowledge acquisition and scientific literacy, informal science learning environments promote a greater sense of appreciation of science and a greater awareness of STEM pathways and careers (Anderson et al., 2021; Markowitz, 2004; Xia et al., 2024). The development of *STEM identity* is also an important personal attribute developed by informal learning environments with Goff et al. (Goff et al., 2020) showing that students with prior informal science and math experiences reported stronger STEM identity and higher aspirations for STEM careers in their university years. Similarly, Luehmann (Luehmann, 2009) reported that students from under-resourced schools who participated in science enrichment programs developed a stronger sense of belonging and confidence in STEM subjects.

STEM study and career aspirations: Many studies (Dabney et al., 2012; Dorsen et al., 2006; Henriksen et al., 2015; Kong et al., 2014) argue that informal STEM experiences provide a critical link between early science exposure and long-term STEM study and career choices, particularly for students from underrepresented groups (Dorsen et al., 2006). Australian studies by Coventry and Woolnough (Coventry, 1997; Woolnough, 1994) show that engaging with informal science learning experiences encourages students in post-compulsory science studies at school and to pursue science careers (Woolnough, 1994); and specifically, in Perth, Western Australia, Coventry found that 80% of students studying STEM based degrees had informal learning experiences by visiting the local science centre, compared to 64% of students who were not studying STEM (Coventry, 1997).

Additionally, Berg et al. (Berg et al., 2021) highlights that out-of-school STEM programs offer unique opportunities for students to develop 21st-century skills such as problem-solving, critical thinking, and teamwork, which are crucial for STEM careers.

ENGAGING STEM-ENGAGEMENT PROFESSIONALS: Aside from engaging directly with informal learning places and programs, there is also great value for community science programs in connecting with the STEM engagement professionals who facilitate and manage these experiences. These professionals have expertise in designing community engagement programs and educational experiences for students, as well as knowledge of working with specific audiences, such as Indigenous communities or youth from low socioeconomic backgrounds (Garbarino et al., 2020). They also often provide professional learning opportunities that equip scientists or members of the public with the skills and confidence needed for effective outreach.

Accessing the knowledge and skills of these STEM engagement professionals can be valuable, particularly in terms of the following:

Education and pedagogical knowledge – STEM engagement professionals typically employ evidence-based learning and teaching approaches to design and deliver activities that promote active participation and deep conceptual understanding. This is important for developing scientific literacy and critical thinking skills.

Audience-centred program design – STEM engagement professionals design programs that meet the needs, interests, and cultural contexts of diverse audiences. They are typically trained for, and more attuned to, the cultural nuances and systemic challenges faced by underrepresented groups. This knowledge is vital for ensuring that community science programs are accessible and relevant for all.

Communication expertise – These professionals are generally adept at simplifying complex scientific concepts without compromising accuracy or quality. They often utilise storytelling approaches, analogies, and interactive role-playing methods to make science relatable and engaging. Effective science communication strategies are especially important for engaging young audiences and audiences with limited prior exposure to science.

Networks, collaborations and partnership building – STEM engagement professionals typically have a well-developed network of scientists, educators, industry experts, and outreach specialists, as well as having experience in building partnerships with schools, universities, community organisations, industry and government stakeholders. Such collaborations can enhance the reach and impact of community science engagement programs, particularly in underserved areas.

Evaluation and continuous improvement – STEM engagement professionals are generally required to employ rigorous evaluation methods to assess program impact and effectiveness. Adopting and/or adapting existing methods of evaluation approaches can make program evaluations more feasible by having access to proven approaches and reducing the cost and expertise needed to develop new evaluation approaches from scratch.

5.5.2 How to connect with and leverage informal learning places and programs

The number and variety of informal science learning places and programs across Queensland and Australia is extensive. Connecting with and leveraging these resources can significantly enhance community science engagement programs. The following sections outline practical approaches for identifying, connecting with, and maximising the opportunities afforded by informal learning experiences.

CONNECTING TO PLACES AND PROGRAMS: Informal learning places include a broad spectrum of venues that cater to different aspects of science engagement. Museums, zoos, aquariums, and planetariums provide engaging exhibitions, while science centres, makerspaces, botanic gardens, marine discovery centres, and observatories allow for hands-on and immersive experiences. Additionally, national parks, libraries, Indigenous cultural centres, and digital media platforms serve as vital spaces for lifelong learning in science.

Beyond physical locations, a wide range of structured STEM engagement programs exist across Queensland and Australia. These include citizen science projects, after-school STEM clubs, university outreach initiatives, environmental conservation groups (such as Landcare and waterway monitoring programs), and industry-led science engagement activities. Other major programs include science festivals, National Science Week events, school holiday STEM workshops, coding competitions, robotics challenges, and hackathons.

Building Partnerships: Connecting and partnering with informal learning places and programs requires the same strategic approach outlined in *Chapter 4.5.2 on collaborative advantage*. Approaching potential partners with an understanding of their mission, goals and objectives and demonstrating how collaboration can support the organisation will make the case for engagement more compelling.

To assist in connecting with informal science learning providers, some suggestions are provided in **Appendix K**.

SITUATIONAL VS INTRINSIC INTEREST – A PRACTICAL APPROACH FOR LEVERAGING INFORMAL LEARNING ENVIRONMENTS: One effective approach to maximise informal learning experiences for participants is by leveraging their ability to stimulate '*situational interest*' (a short-term spark of curiosity) and converting it into '*intrinsic interest*' leading to long-term engagement in STEM (Palmer, 2004; Palmer et al., 2017). For example, community science engagement can utilise informal learning places or programs to capture participants' immediate curiosity through hands-on, engaging activities, and then build on that interest by providing opportunities for deeper exploration and personal connection to STEM over time.

Situational interest – capturing immediate engagement: Research consistently demonstrates that informal learning experiences are highly effective at generating situational interest (Neher-Asylbekov & Wagner, 2023). This occurs through:

- Engaging and interactive hands-on activities which trigger curiosity (Bathgate et al., 2014). For example, exposure to scientific demonstrations with surprising outcomes or discrepant events, and those with sensory-rich digital experiences, can create awe and excitement for participants (Renninger, 2007).
- Experiencing exhibits and programs that link science to everyday life and global challenges, increasing both interest and appreciation for science (Renninger, 2007).
- Science being presented using relatable characters, compelling storytelling, historical discoveries, or futuristic scenarios, strengthens emotional connections to science.

From situational to intrinsic interest – ensuring long-term engagement: Intrinsic interest represents a deeper, self-motivated connection to science. To encourage participants to continue engaging with science beyond their visit to an informal learning place or program, community science programs can provide structured opportunities that reinforce and expand upon their experiences. Some suggested approaches include:

- Following up the informal learning experience with progressively scaffolded, more complex, activities that allow learners to deepen their understanding of the scientific concepts encountered during their visit.
- Encouraging participants to replicate experiments or experiences at home, allowing them to further explore scientific concepts in their own environment.
- Assigning STEM challenges or competitions related to what they explored, to reinforce learning and sustain engagement.
- Providing participants with opportunities to explore topics that align with their own interests, increasing intrinsic motivation and long-term engagement.
- Introducing potential mentors and role models (e.g. relatable scientists, STEM professionals, educators) will help participants develop a sense of belonging in science and visualise a future with STEM studies and careers.
- Encouraging reflective activities relating to their visit, such as journaling or a presentation to family and friends, leading to a deeper personal connection to science.

Informal learning places and programs offer powerful opportunities to spark curiosity and excitement in STEM, creating opportunities for facilitating ongoing engagement. Strategic partnerships with these environments can significantly enhance the reach and impact of community science engagement programs.

5.6 Connecting with Formal Education – Creating the 'Third Space'

This principle recognises the importance of formal, school-based learning of science and how community science engagement programs can enrich and extend this learning by creating a 'third space' connecting curriculum-based learning with students' own lived experiences, cultures, and real-world contexts.

5.6.1 Why connect with formal science education

The following discussion firstly articulates the current nature of formal science education in Australia, with implications for developing scientific literacy and, more broadly, science identity and science capital. This is followed by an appraisal of the importance of, and benefits gained by, connecting community science engagement programs directly connecting with formal education systems.

The Evolving Purpose of Formal Science Education: Australia's national curriculum (ACARA, 2025) provides the following, as part of the rationale for science education in Australia: *"The Australian Curriculum: Science enables students to develop an understanding of important science concepts and processes, the practices used to develop scientific knowledge, science's contribution to our culture and society, and its uses in our lives."*

To achieve these outcomes, science education in Australian schools is organised under three inter-related strands:

Science understanding – students develop knowledge of key scientific concepts, principles, and models and learn to apply this knowledge to explain phenomena, make predictions, and solve problems in familiar and unfamiliar contexts. This strand encompasses four sub-strands – *Biological Sciences; Earth and Space Sciences; Physical Sciences;* and *Chemical Sciences*.

Science Inquiry – students learn how to think and work like scientists by developing inquiry skills to pose questions, design and conduct investigations, analyse and interpret evidence, and communicate findings. They apply critical and creative thinking to evaluate claims and build evidence-based conclusions. This strand encompasses five sub-strands – *Questioning and predicting; Planning and conducting; Processing, modelling and analysing; Evaluating;* and *Communicating.*

Science as a Human Endeavour – students explore science as a dynamic, evolving field that is influenced by, and in turn influences, society. They learn about the role of scientific inquiry, how scientific knowledge develops over time, and the ethical, cultural, and societal contexts that shape scientific practice and application. This strand encompasses two sub-strands – *Nature and development of science;* and *Use and influence of science.*

Scientific literacy as the basis for science education: The structure of the *Australian Curriculum: Science* aligns with (recent) past notions of the purpose of science education being intimately tied to the development of student scientific literacy (Bybee, 1997; Goodrum et al., 2001; Goodrum & Rennie, 2007; Leonie J Rennie et al., 2001). Accordingly, the three strands of the *Australian Curriculum: Science* align tightly with the three key aspects of scientific literacy, namely:

- **Content Knowledge –** understanding fundamental scientific concepts and principles
- **Understanding Scientific Practices –** knowing how scientists do science by inquiry – i.e. designing and conducting investigations, gathering evidence, and drawing evidence-based conclusions
- **Understanding Science as a Social Process –** Recognising that science is a human endeavour with social, cultural, and ethical dimensions.

The OECD Program for International Student Assessment (PISA) proposes *"a conception of scientific literacy as the outcome of science education and the central concept for science assessment"*. In its 2006 framework, this was framed as follows (OECD, 2006) (p 23):

- An individual's scientific knowledge and use of that knowledge to identify questions, to acquire new knowledge, to explain scientific phenomena, and to draw evidence-based conclusions about science-related issues
- Understanding of the characteristics of science as a form of human knowledge and inquiry – including the scientific method, evidence-based reasoning, ethics, scientific uncertainty, consensus and risk
- Awareness of how science and technology shape our material, intellectual and cultural environments, and willingness to engage in science-related issues, and with the ideas of science, as a reflective citizen.

Once again, the close alignment between scientific literacy and the purpose of science education is apparent.

Interestingly, however, the 2025 draft PISA framework has been modified to "one which is broader" with the focus now on *"the general outcomes of science education … and not specifically on 'science literacy' "* (OECD, 2025).

Science identity and science capital: The new 2025 PISA framework introduces *science identity* and *science capital* as new constructs against which student success in science education will be measured. The rationale given for this inclusion has been articulated:

"… *while scientific knowledge and competencies are important and valuable for young people's futures, identity outcomes are also crucial for supporting agency and active citizenship in a rapidly changing world. Such outcomes are the extent to which young people feel meaningfully connected to science, recognise themselves and feel recognised by others as science interested/competent, and engage with the sciences as critical consumers and decision-makers in their daily lives"* (OECD, 2025).

As yet, there has been no overt shift in the *Australian Curriculum: Science* to include science identity and science capital components and, on the surface at least, the framing of the current science curriculum still seems rooted in the notion of student scientific literacy. Herein lies a potential opportunity for community science engagement programs – i.e., to work proactively with schools and teachers to develop professional learning targeting science identity and science capital.

It should be noted that some early work to include these affective domains into science education has been undertaken within the Australian Academy of Science *Primary Connections* program, which (as noted in Chapter 5.1) has adapted its inquiry-based learning framework to encapsulate science identity and science capital (PrimaryConnections, 2024). In addition, several recent Australian studies have explored aspects of science capital with students (Cooper et al., 2022; Stahl et al., 2021) and teachers (Godfrey Lopez, 2024).

The Importance of Engaging with Formal Education: In the early 2000's, several landmark reports painted a "bleak" picture of the quality of learning and teaching of science in Australian schools (Goodrum et al., 2001; Goodrum & Rennie, 2007; L.J. Rennie et al., 2001; Leonie J Rennie et al., 2001; Tytler, 2007). Findings showed primary schools giving inadequate attention to science by teachers lacking confidence to teach it and secondary school science characterised by disengaged students, irrelevant content and out-of-field teaching – all leading to declines in civic scientific literacy and relative declines in post-compulsory STEM studies (ACER, 2018). These trends have had a significant effect on tertiary enrolments in STEM, contributing to a shortage of STEM qualified workers (PWC, 2015).

Student disengagement with science studies, particularly in junior secondary school, has been attributed to several factors including a lack of interest in science, its perceived difficulty, limited understanding of the opportunities afforded by studying science, and (most significantly) the lack of relevance to students' everyday lives and the world around them. The traditional emphasis on teaching abstract, discipline-bound 'canonical' science content using transmissive pedagogies in school settings does not resonate with student self-identities, and alienates students by failing to connect science to their current interests and future aspirations (Goodrum & Rennie, 2007; Tytler, 2007) – *"When students move to high school, many experience disappointment, because the science they are taught is neither relevant nor engaging and does not connect with their interests and experiences"* (L.J. Rennie et al., 2001).

This has led calls for a *"*reimagining of science education*"* that emphasises relevance, personal meaning, and connection to students' lived experiences (Tytler, 2007). Researchers and policymakers now advocate for pedagogical approaches grounded in inquiry-based constructivist principles, integrated with students' cultural backgrounds and real-world applications, promoting science identity and science capital, alongside the development of scientific literacy – making science meaningful both within and beyond the classroom (Goodrum & Rennie, 2007; Tytler, 2007).

A third space is needed in Australian science education: Among proposed solutions to the problems outlined above, scholars have called for embedding informal science spaces and community science engagement programs into the mainstream delivery of school science (Braund & Reiss, 2006; Gomes & McCauley, 2013; Goodrum & Rennie, 2007; McCauley et al., 2018; Rennie, 2006; Stocklmayer et al., 2010; Tytler, 2007) – thereby creating the so called 'third space', a hybrid learning environment where formal and informal sectors collaborate. This space blends structured curriculum with the flexible, engaging, real-world experiences that only resources from informal learning spaces and community outreach programs can provide. This offers students the opportunity to integrate their own personal experiences, interests and cultural knowledge with structured learning.

A comprehensive US report from the Centre for Advancing Informal Science Education (CAISE, 2010) argues that no single institution can achieve the broad goals of science on its own. A rich science education requires the combined efforts of schools and informal science education programs to deliver engaging, authentic, and culturally responsive learning. Rather than viewing these programs as supplementary, the report argues they should be seen as a core component of a coherent and equitable science education system.

While the concept of a third space has considerable international support (Braund & Reiss, 2006; Gomes & McCauley, 2013; Martins Gomes & McCauley, 2016; McCauley et al., 2018) it has also been significantly advanced within the Australian education landscape. A range of scholars and policy initiatives have emphasised the importance of connecting formal school science with community-based learning opportunities, including partnerships with local industry, science outreach programs, and informal science learning spaces.

For example:

- Goodrum et al. (Goodrum & Rennie, 2007) argue that *"Effective science education brings school science and the out-of-school science community much closer together. This is a powerful way to enhance science learning because it shows students that science has demonstrable relevance and value to them, and provides opportunities for them to see science in action and to use science in their life outside of school"* (Goodrum & Rennie, 2007).
- Tytler (Tytler, 2007) highlights the importance of linking schools with science in the community, including local industry, community issues, and science outreach initiatives and notes that *"School and community-linked projects hold the promise of satisfying many of the conditions for an engaging and meaningful science education".*
- Rennie (Rennie, 2006) argues that students are likely to engage with science in community settings after leaving school; it is therefore imperative that school science education reflects and models these real-world settings within the curriculum.
- Stocklmayer et al. (Stocklmayer et al., 2010) advocate for a third space where *"the formal sector integrates the capabilities of the informal sector into its everyday working"* and further suggest that this *"would enable some of the current challenges to the formal sector to be successfully and speedily met"* and the focus should be *"on the third space as a place in which students can encounter the offerings of the informal sector within the school".*

Reflecting the importance of these ideas, Australia's *National STEM Education Strategy (2016-2026)* (EducationCouncil, 2015), articulates five areas for national action, including Action 4, *"Facilitating effective (school) partnerships with tertiary education providers, business and industry".* This inclusion signals a systemic commitment to integrating school-based science learning with broader community, academic and industry programs to enhance student engagement and science education more broadly.

For the Australian government, connecting community science programs with formal education is not an optional enrichment choice – it is a strategic necessity for revitalising science education in Australia.

THE BENEFITS OF CONNECTING WITH FORMAL EDUCATION: Connecting community science engagement programs with formal, classroom-based, education settings represents a clear example of collaborative advantage, where mutual access to resources and expertise not only strengthens each partner's capabilities but also results in the creation of new value together – namely, enriched learning experiences and improved outcomes for students. These benefits also extend to teachers, schools and the community engagement program itself.

Enriching student learning through relevant inquiry: Relevance is key. Community science programs are uniquely positioned to bring scientific concepts to life by offering schools fresh perspectives, expertise, meaningful (and local) contexts, and resources that make science accessible and compelling for students.

They offer access to real-world phenomena, authentic data sets, practicing scientists, and industry collaborations that provide students with experiences that go beyond textbook-based instruction. By participating in community-led programs and investigations (e.g. monitoring local waterways or engaging with local industries) students connect to real-world contexts and issues of local relevance, allowing them to see the significance of science to their lives.

These learning environments also encourage exploration, observation, and curiosity, which are central to the inquiry-based learning approaches now required in formal education settings.

Affective and culturally responsive engagement: Emotional engagement plays a significant role in science learning and is central to ongoing, post-compulsory, engagement in formal science education. Affective engagement through enjoyment, curiosity, wonder, and relevance can be leveraged by informal learning programs in ways that schools find difficult to mimic, but should intentionally adopt (Stocklmayer et al., 2010).

Community science programs also often succeed where schools struggle in terms of personalised, culturally relevant connections that validate students' identities and lived experiences. Formal classrooms often reinforce narrow views of who belongs in science, shaped by Western values and content, conventional assessment approaches and exposure to traditional stereotypes.

Locally operated community programs can promote inclusivity by tailoring programs to reflect the cultural knowledge and community values of participants. This is especially important for students from under-represented communities, who may not see themselves reflected in traditional science curricula. Community science programs also generally have greater access to a broad range of engaging science role models and industry mentors, helping students to build the social connections required to sustain long-term interest in science and facilitating career pathways through industry connections and experiences.

These capacities can transform a student's perception of science from one of alienation to one of belonging. When schools align their curriculum with these community-driven approaches, they can enhance not only academic achievement but also science identity and science capital – ultimately shaping future engagement and aspirations.

Teacher professional learning: Schools also stand to gain significantly from these partnerships through ongoing teacher professional development which is often a core component of successful formal-informal partnerships (CAISE, 2010). Teachers are provided with rich content knowledge, access to specialised resources, infrastructure and expertise, allowing them to experiment with a greater range of student-centred experiences. Additionally, when schools and community science programs co-design learning activities, such as university laboratory experiences or afterschool science clubs, they promote curricular alignment. This is particularly valuable for reinforcing core, in-class, concepts and assists in bridging what students are learning in class with what they are exploring outside it, creating a cohesive learning experience across formal and informal settings.

Benefits for community science programs: The benefits of connecting with formal education extend equally to community science programs. Partnering with schools expands the reach and impact of community programs, particularly among diverse and underserved student populations who may not otherwise engage, or have access to, informal science learning spaces.

Working with educators also helps community programs tailor their offerings to meet curriculum goals and formal learning outcomes, enhancing their impact and relevance to their local communities, as well as demonstrating value to funders and other stakeholders. Moreover, successfully connecting with schools will lead to more consistent participation, rather than one-off visits, facilitating long-term program sustainability and scalability.

5.6.2 How to connect with formal education

As noted in Chapter 5.4, teachers are time poor and the overriding educational priorities of schools involve reporting student learning outcomes against a rigid and packed curriculum. Planning to connect with the formal education sector will need to take these priorities into account.

Intentional, sustained collaboration: For all the above benefits to be realised, partnerships must be thoughtfully designed and sustained over time. One-off visits or guest talks, while enjoyable, rarely lead to lasting change. Effective collaboration requires long-term shared goals, joint planning, clear communication, and mutual respect between formal and informal educators (CAISE, 2010; Stocklmayer et al., 2010). Designing collaborations with the formal education sector that align to Kanter's six principles of *Collaborative Advantage* will be a good starting point (Chapter 4.5).

At its core, however, the relationship must align to the key purpose of science education, namely the development of student scientific literacy; ideally the design of engagement programs and activities would also include strategies that address the science capital of students. In practice, this will depend on the specific needs of teachers and schools and the capacity and capabilities of the community engagement team. For example, it might mean community science programs engaged in:

- co-developing curriculum aligned lesson plans
- aligning program activities with classroom topics
- developing and delivering professional development opportunities for teachers
- provision of resources infrastructure, facilities or expertise that schools lack
- linking schools to industry professionals, community groups or the university sector, and
- provision of engaging hands-on experiences not afforded by the formal schooling system.

Making the community's contribution count: In the final section of her 2006 paper (Rennie, 2006), Rennie argues that if the goal of school science education is to promote scientific literacy, then teaching must focus on developing the underlying skills and abilities that support this concept. She notes that effective partnerships with the community—such as excursions, incursions, and collaborative projects—align well with these goals when they are integrated into the curriculum, not treated as optional add-ons. Rennie concludes with three simple rules about using community resources successfully:

1. **Integration –** experiences with community resources are integral, not peripheral, to science at school
2. **Preparation –** teachers and students understand what the tasks and expected outcomes are and what needs to be done to achieve them
3. **Accountability –** teachers and students are jointly responsible for ensuring task completion.

Based on observations of successful community programs connecting formal education, Rennie further articulates the following Guiding Principles for the success of these community-school programs:

- they are based on some *issue/stimulus that comes from the community* and is not imposed
- they require *local knowledge* to ensure input of community members
- they are *educative*, because they focus on science as a way of knowing, thinking and acting, and they model science inquiry (i.e., working scientifically)
- they are *integrated into science at school* and so legitimise participation by students and teachers
- they *involve negotiation and decision-making with the community* in regard to:
    - social, political and economic factors
    - differing perspectives from different groups, and
    - information collected (both local and science-related), and
- they have a *tangible outcome* to indicate when the project is complete and has achieved something worthwhile.

The suggestions, observations and examples provided above regarding how best to connect to the formal education sector will help ensure that engagement efforts are relevant and align to the realities of school contexts. By aligning with curriculum goals, supporting teachers, and engaging in co-designed programs, these approaches offer a practical approach to connecting with the formal education sector.

5.6.3 Case study: Science on the GO!

Launched in 2005, *Science on the GO!* (SOTG) is Griffith University's flagship STEM outreach initiative, developed to address declining interest and performance in science education across Queensland's Gold Coast and Logan regions. These regions, lacking informal science learning institutions such as museums or science centres, presented a unique need for community-based interventions to raise science literacy and engagement. SOTG's mission is to facilitate pathways to tertiary STEM success, particularly in underrepresented communities, through direct engagement with students, teachers, parents, and the wider community. With over 650,000 engagements to date, SOTG has delivered more than 50 distinct programs across school and community settings, becoming a model of sustainable and scalable outreach.

A defining strength of SOTG is its long-standing, deeply embedded partnership with the Southeast Education Region (SER) of Queensland's Department of Education. This collaboration exemplifies Kanter's six principles of "Collaborative Advantage." The partnership was driven by a mutual recognition of the *importance* of improving science education outcomes. SER brought *excellence* in teacher networks and access to over 250 schools, while Griffith contributed university expertise and resources. Their ***interdependency*** is most clearly illustrated by the secondment of SER teachers to SOTG—working from Griffith's offices for more than 15 years—allowing for the co-development of teacher professional learning and student programs (*co-investment*). This embedded presence also speaks to *integration*, with staff working seamlessly across both systems. The model has *evolved* to become a catalyst for state-wide initiatives, including the creation of the Queensland STEM Education Network (QSEN), a university consortium scaling the SOTG model across Queensland.

The outcomes of this partnership are profound and far-reaching and measurable. Over 17,000 teacher professional learning engagements have enhanced classroom practice and contributed to improved student outcomes in STEM, while the *Griffith STEM Ambassador School Program* has enabled schools to develop whole-of-school STEM action plans that have increased participation in senior science subjects and led to a 25% rise in STEM-related pathways in participating schools. The partnership has also fostered increased enrolments in Griffith's STEM degrees, with local data showing strong correlations between program engagement and students' university study decisions.

Through structured engagement across the student lifecycle (from early primary school through to tertiary transitions), SOTG offers a holistic, community-embedded model for building science capital. By working in genuine partnership with the formal education sector, and by aligning with best practice principles of collaboration and STEM engagement, SOTG serves as an exemplar of how community science programs can connect to formal education sectors to drive lasting, systemic change in STEM education.

5.7 Leverage Local Knowledge, Contexts and Resources

This principle recognises the importance of local 'assets' to community science engagement programs and the value of working with communities as true partners in science engagement. When community science engagement is informed by, and emerges from, local people, expertise and resources, programs are more likely to excite local interest, be inclusive of all community members and give rise to long-term sustainability.

5.7.1 Why leverage local assets?

Historically, community engagement programs have often developed from a deficit perspective, with a focus on what a community lacks or what they are perceived to need. An asset-based community approach starts with the premise that all communities have rich assets that can be leveraged to promote engagement and learning. Rather than focusing on what under-resourced communities may lack, this approach focuses on what they *do* have – for example, people, local knowledge, cultural traditions, community organisations, industry, infrastructure, and community leaders who can champion science.

By tapping into these assets, community science programs not only engage participants more effectively in STEM but also strengthen local community networks, build community capacity, and promote a sense of ownership and pride. Thus, creating lasting benefits that extend beyond the immediate program outcomes.

An Engaged Community versus a Community Engaged: When a community is engaged in identifying its own assets, the focus tends to remain on the inherent strengths of the people in the community and what they can offer to make their communities better (García, 2020; Kretzmann & McKnight, 1996). Community members therefore feel empowered and are more likely to think that their involvement in community work can and will be truly meaningful.

From this perspective, community science engagement will not be an abstract engagement with scientific ideas, passively received from an outside facilitator, but a process of collaborative participation in a community of practice. When engagement activities are tied to local places and real-world local issues, participants engage in authentic scientific practices (Bonney, Cooper, et al., 2009; Bonney et al., 2016). This aligns with the idea that engagement and learning in science is *"a social process tied to 'place', in which groups of people with complementary expertise (and interests) work together"* (Kelly & Bell, 2012).

In community co-designed programs, participants bring their own experiential expertise (e.g. knowledge of local conditions, cultural practices, and community needs) which complements science content and science approaches delivered by program facilitators. This creates a two-way learning exchange where programs are not only co-designed, but participants and facilitators engage as co-learners.

Moreover, this 'place-based learning' approach increases engagement because participants find the activities relevant and authentic, supporting deeper learning because new knowledge is immediately applied to a familiar context (Coker, 2017; Sarkar & Frazier, 2008). In short, local content and contexts function as 'hooks' that draw participants in and serve as the foundation for ongoing engagement and learning (Stilgoe et al., 2014).

A final important point about co-designed community programs is that they help young people develop broader perspectives on who does science, how and where it is done, and how it connects to their lives and the betterment of their communities. Participants see science done *"where they live, by people like them, and for issues they face"*, expanding their notions of who can be a legitimate contributor to scientific endeavours (Kelly & Bell, 2012).

CULTURALLY RESPONSIVE COMMUNITY ENGAGEMENT – PROMOTING EQUITY AND INCLUSION: The importance of science capital with regard to attitudes and aspirations in science (Chapter 3.2) shows that an individual's ongoing engagement with science is influenced not only by what they know, but also by their cultural background, social networks, and personal experiences. This not only requires intentionally situating science engagement programs within local contexts (connecting to familiar places and issues) but also designing programs that build on their cultural identities, cultural knowledge and cultural networks. Unfortunately, however, science education and community science programs are too often presented as a one-size-fits-all approach shaped by dominant Western norms – the so-called 'WEIRD' view of science (Western, Educated, Industrialised, Rich, Democratic) (Henrich et al., 2010). This approach can alienate historically marginalised groups, reinforcing stereotypes about who belongs in science and who does not.

Culturally responsive community engagement provides ways to address this challenge, promoting equity and inclusion and improving the science capital of participants. Culturally responsive science engagement leverages the cultural knowledge, prior experiences, identities and values of participants to make science more relevant and valuable for them (Council, 2012). By aligning scientific content with people's everyday lives, values, and concerns, culturally responsive community engagement makes science more accessible and meaningful. It actively works to challenge exclusionary narratives and stereotypes about who belongs in science, while supporting a sense of ownership and connection among participants—particularly those from historically underrepresented communities (Council, 2012).

But culturally responsive engagement also goes beyond merely recognising and celebrating cultural diversity (Vass, 2017), it explicitly *accounts* for the cultural beliefs and values of participants (Doucet, 2017). It not only works to affirm these affective community assets, but overly integrates them into program design and delivery, ensuring that science is not only understood but also *felt* to be relevant.

Culturally relevant science engagement therefore provides a powerful framework for equity and inclusion. Community science program designers are therefore encouraged to move beyond deficit views of engaging underrepresented communities and recognise community diversity as an asset that is fundamental to meaningful and responsive science engagement.

PROGRAM SUSTAINABILITY: When communities see science as directly tied to their lives and concerns, they are more likely to find it meaningful and inclusive, and something worth engaging with over time. Leveraging local contexts and resources therefore contributes to long term sustainability of community engagement efforts. Programs rooted in local priorities are more likely to gain community buy-in and more able to develop partnerships with local organisations and industries. They are also more likely to enlist local leaders as program champions and recruit (and train) individuals to facilitate program activities. Programs co-designed and co-delivered *"with and in local communities"* create more connected, resilient networks for STEM engagement learning (Bevan et al., 2018).

By treating community members as equal partners in co-design and co-delivery, community programs demonstrate genuine respect for local communities and their cultures and histories. This, in turn, enhances trust, which is the bedrock of long-term, sustainable engagement.

In summary, the rationale for leveraging local content, contexts and resources is strong:

- it enhances engagement by making science personally relevant
- it promotes inclusion by valuing participants' knowledge, culture and values, and
- it builds a foundation for long-term, self-sustaining science engagement within marginalised and underrepresented communities.

5.7.2 How best to leverage local assets

Translating the above principles into practice requires intentional approaches to initial engagement, design and delivery of programs that truly reflect local contexts and make use of community assets. Assessing existing community assets and building partnerships with local individuals and organisations is fundamental for creating relevant programs. Local leaders can provide insights into community interests, needs, and values that should shape the program's focus. Working with these stakeholders from the outset helps to ensure the program's goals and objectives align with local priorities and encourage community buy-in.

Below are key strategies and approaches, drawn from research and practice, for incorporating local content, individuals and resources into community science engagement programs by:

- Assessing community STEM assets and developing a shared vision
- Introducing citizen science projects as a mean of leveraging community STEM assets
- Addressing First Nations Peoples notion of *'Country'* as an asset for culturally responsive engagement.

These strategies align with the best-practice principles already outlined in this Guide and should be considered in conjunction with Chapter 3.2 (science capital), Chapters 4.1–4.6 (core design principles – and especially Chapter 4.6, *Accessibility and Inclusivity*) and Chapters 5.1–5.6 (science engagement principles). See **Appendix L** for some links on Leveraging Local Assets.

Assessing Community Assets and Building a Community Vision: Community asset mapping (or capacity and capability mapping) is a participatory approach that focuses on mobilising existing local assets – including people, skills, stories, knowledge, organisations, and natural resources (García, 2020; Kretzmann & McKnight, 1996; Kretzmann & McKnight, 1993; Scott et al., 2020). It supports community ownership, participation, and long-term sustainability – shifting the narrative from community deficit to community potential.

Cunningham et al. (Cunningham & Mathie, 2002) outline a step-by-step approach that community science engagement programs can adopt to map community assets and build a joint vision for science engagement:

1. **Collecting stories –** begin by facilitating conversations that highlight past community successes. These stories uncover both individuals', and the broader community's, hidden talents and skills, and helps boost confidence and pride in local capacity. Start with local school leaders, civic leaders, cultural knowledge holders (e.g. elders), and youth mentors etc.

2. **Organising a core group –** As stories are collected, natural leaders will emerge. This group will typically have broad community networks and personal passions that drive their engagement. This group engages others through their networks and shared motivation.

3. **Mapping assets –** These individuals are now ready to identify and document the following:
    - Individual talents/skills/capabilities – e.g. educators, STEM professionals, tradespeople, artists etc.
    - Local associations and informal groups – e.g. Rotary clubs, sports clubs, faith groups, Landcare groups etc.

- Institutions – e.g. schools, universities, businesses, NGOs, and libraries (and other informal learning places)
- Natural and physical assets – e.g. water resources, land and community infrastructure that could be utilised.

Mapping is done *by* the community to build relationships and identify development opportunities.

4. **Building a community vision and plan –** A broad group creates a shared vision and selects a practical asset-based program of activities that can be readily implemented and achieved. While the expertise and recourses of the science engagement program can be incorporated into this project at this point, this stage of development still prioritises local leadership, ensuring program leaders take a supporting, not controlling, role.

5. **Leveraging external resources –** Only after local resources are mobilised do program leaders assist communities in seeking outside support – e.g., funding. This sequencing ensures communities approach external actors from a position of strength, with a clear vision and demonstrated local commitment. External resources need to be aligned to support *locally defined* priorities, not donor-driven demands.

Co-design and co-deliver the program: Having established a broad vision for community science engagement and having chosen an appropriate project/program utilising community assets, it is time to design and deliver the specifics of program. A hallmark of leveraging local context and resources is engaging community members not just as learners, but as active partners in the co-design and co-delivery of science engagement programs.

Co-design means close collaboration with community stakeholders rather than imposing external “experts” to unilaterally determine what is best for local community engagement. Here the six *Core Design Principles* detailed in Chapter 3 are highly relevant, for example:

1. Identifying an overarching goal (or goals) to align with the community inspired vision; and articulating SMART objectives for each goal
2. Creating an evaluation plan, deciding on evaluation methods and the stakeholder audiences that will be targeted for evaluation
3. Evaluating (or re-evaluating) program and community capabilities/capacities developed during the asset mapping process above
4. Giving early consideration to program sustainability and scalability
5. Continuing to develop ongoing strategic community collaborations and/or partnerships based on the community mapping exercise above
6. Considering inclusivity and accessibility considerations not already addressed during the asset mapping process.

Co-delivery is equally important. Empowering community members to take on roles as facilitators, co-presenters, or mentors will signal shared ownership and ensure that programs remain culturally relevant and grounded in community priorities. This may require building local capacity by providing local training or professional development to run activities; or having a local farmer or STEM professional share on-site, real-world, insights as part of program activities. Additionally, one or more of the science engagement principles outlined above in Chapters 5.1–5.6 will be relevant.

CITIZEN SCIENCE – AN EXAMPLE OF SITUATED, PLACE-BASED, ENGAGEMENT: Designing activities based on scientific issues that directly impact the local community can greatly increase engagement. Additionally, evidence shows that learners in community science programs are more motivated when they see an authentic purpose for learning (Braund & Reiss, 2006; Habig & Gupta, 2021; Hellgren & Lindberg, 2017; Renninger, 2007).

Place-based citizen science programs involve citizens from the non-scientific community in academic research (Tulloch et al., 2013), typically in collaboration with (or under the direction of) professional scientists and scientific institutions (Irwin, 2015). Bonney et al. (Bonney, Ballard, et al., 2009) identified the most effective citizen science initiatives involved a co-created model where community members and scientists jointly design the research. This approach *"places local or regional issues at the heart of the research"* and they aim to *"meet people where they are geographically, intellectually, and in terms of values, interests, families, and jobs"* (Bonney et al., 2016) – making science more accessible and relevant to diverse participants. This approach attracts audiences who might not otherwise engage with science and ensures that community members see their own values and knowledge reflected in the project (Bonney et al., 2016).

There is evidence that involving community members from the earliest stages, when research questions and experimental design approaches are decided, makes the research more effective in the local context (Taffere et al., 2024). In fact, projects of this kind can influence which research questions are asked in the first place, providing the initial rationale for community engagement (Bonney et al., 2016). This means that scientific investigations are not just done *in* the community, but *with* the community. Such contributions enrich the science and give participants a sense of ownership and pride in the outcomes.

Citizen science also builds social and science capital by connecting people and groups. A recent systematic review found that many citizen science efforts report gains in *"community connectedness and cooperation"* among volunteers (Ballard et al., 2024). Notably, these outcomes are strongest when people are involved not only in collecting data but also in planning, analysing, and discussing results (Ballard et al., 2024).

A practical model for developing a citizen science project: Based on long-term research and practice at the *Cornell Laboratory of Ornithology*, Bonney et al. (Bonney, Cooper, et al., 2009) have established a framework for developing and readily implementing a citizen science project. The framework is based on the following sequenced steps:

1. Choose a scientific question.
2. Form a scientist/educator/technologist/evaluator team.
3. Develop, test, and refine protocols, data forms, and educational support materials.
4. Recruit participants.
5. Train participants.
6. Accept, edit, and display data.
7. Analyse and interpret data.
8. Disseminate results.
9. Measure outcomes.

The model advocates starting with a well-scoped scientific question, forming a multidisciplinary team, and developing robust data collection protocols and educational materials. The paper provides a detailed and practical description of each step, making it a useful guide for both scientists, educators and the public.

Australian citizen science programs: Australia offers excellent examples of leveraging local assets through citizen science programs. The Australian Citizen Science Association (ACSA) serves as a central hub for promoting and supporting citizen science initiatives, providing resources, opportunities and showcasing best-practice programs across the country. Some examples include:

- The *Atlas of Living Australia* provides nationwide infrastructure to support hundreds of community-led projects, with around 50% of Australia's biodiversity records contributed by citizen scientists.
- *ClimateWatch* enlists everyday people to record seasonal changes in their area, drawing on their local knowledge of nature to help track climate change impacts.
- The *Reef Life Survey* engages recreational divers and the dive industry in monitoring marine life on local reefs, turning enthusiasts and tourism operators into key partners in scientific data collection.

By building on what communities already have (e.g., local knowledge, cultural traditions of observing Country, or networks of volunteers), citizen science programs provide a vehicle for inclusive participation in scientific discovery, turning local assets into drivers of scientific and social benefit.

'COUNTRY' – A CULTURALLY RESPONSIVE APPROACH FOR ENGAGING FIRST NATIONS COMMUNITIES: Chapter 4.6 of this document introduced culturally responsive pedagogies as a means of effectively engaging First Nations communities in science engagement programs. Building on those ideas, this section highlights one of the most foundational and distinctive assets that First Nations communities bring to any engagement context – the notion of '*Country*'.

For First Nations Australians, *Country* is not simply land or a geographic location found on a map. It is a word that holds many different meanings for the wide diversity of First Nations people across Australia – but there are certain concepts and ideas that are shared. *Country* is a living entity embedded in both place and relationship; it encompasses identity, kinship, language, law, culture, spirituality, the seasons, land, winds, water, plants, animals, people, stories and relationships with ancestors (Harrison & Skrebneva, 2020). As expressed by Elders in (Harrison & Skrebneva, 2020) *Country* is *"me… it's my homeland, my identity, it's who I am".*

As noted throughout this document, one of the overriding aims of community science engagement programs is to positively affect the science capital of individuals and communities, including notions of 'self-identity' and 'belonging' within science contexts. When engaging with First Nations communities, therefore, it is essential to recognise First Nations science capital (Chapter 4.6) and respect the centrality of *Country* as a source of identity, knowledge, and connection – key aspects of science capital. Community engagement efforts that are grounded in *Country* – that is, designed to align with the values, relationships, and worldviews of First Nations peoples – will result in meaningful participation and a sense of ownership and belonging among Indigenous participants. In addition, the learning outcomes achieved are not just related to traditional assessments and 'closing the gap' targets, but also include outcomes associated with increased community and parental engagement and reconnecting students to their forebears and Elders (Harrison & Skrebneva, 2020) – key components of developing First Nations science capital.

As noted in Chapter 4.6, however, there are views that the structure of *Australian Curriculum: Science* (intended, implemented and received) does not adequately support the development of science capital of First Nations students (Cooper et al., 2024). This presents an opportunity for community science programs to connect with educators in First Nations communities to adopt the most foundational of community assets, the notion of *Country* (including Indigenous ways of learning, knowing and connecting) as part of the design and delivery of programs.

Such an approach moves beyond superficial appropriation of cultural content (as is mostly the case) to a more respectful and meaningful engagement. By adopting an assets-based approach to community engagement, First Nations knowledge systems and perspectives are recognised as rich and valuable assets to be harnessed for advantage, not as challenges to be managed for the sake of diversity and inclusion.

5.7.3 Case Study: Citizen science – the Reef Life Survey

Reef Life Survey (RLS) is a world-leading example of citizen science in action, uniting marine scientists, management agencies, and recreational divers in a global effort to monitor and protect marine biodiversity. Established in 2007, RLS was developed with a key motivation: to make the underwater world more visible and accessible to both the public and decision-makers, and to generate the robust, high-quality data needed for informed marine management and scientific discovery.

By training skilled recreational divers to collect data using standardised scientific methods, RLS extends the capacity of marine research teams and builds long-term monitoring programs in places where traditional scientific teams would struggle to operate due to budget or logistical constraints. Volunteers receive extensive training and work closely with scientists, ensuring a high standard of data quality and contributing meaningfully to ongoing research.

A defining feature of RLS is its strong partnership with management agencies, which help identify priority areas for data collection. This collaboration ensures that RLS data directly inform marine policy and conservation strategies, particularly through adaptive management approaches that rely on timely and long-term datasets. The impact of RLS has been profound, with regular surveys conducted in hundreds of locations around Australia and internationally, including annual monitoring at sites like Rottnest Island since 2008.

RLS also creates deep personal connections between volunteers and the environments they monitor. For divers like Paul Day, a decade-long volunteer, participation in RLS has fostered both environmental awareness and a sense of contribution to meaningful change. Events such as the 2010-11 marine heatwave highlighted the value of RLS data, enabling both scientists and community members to observe and quantify ecological changes.

Today, RLS not only provides essential scientific data but also supports a growing global network of citizen scientists – many of whom have gone on to become professional researchers. It is a compelling model for how community knowledge, skills, and passion can be mobilised to address environmental challenges at scale.

6.0 Program Assessment Guidelines

To support the practical application of the 13 best practice principles identified in this document, two sets of assessment guidelines have been developed. These are designed to guide users in designing, evaluating, delivering and refining community science engagement programs. They can be used in various contexts, by various users including for the creation of new programs, the assessment and enhancement of existing initiatives, or for professional development and reflective practice. The guidelines offer a structured, principles-based framework that encourages continuous improvement and alignment with best practice in community science engagement.

6.1 Assessing Core Design Principles

This guideline aligns with the first six best practice principles, which focus on the foundational elements of effective program design. Each of the six core design principles identified in this document are listed in bold in the left-hand column.

How to Use This Guideline:

1. **Self-Assess**: Rate your current core design principles across each category.
2. **Identify Gaps**: Look for areas where improvement is needed.
3. **Refine and Improve**: Apply best practice principles to strengthen your engagement strategies.
4. **Track Progress**: Regularly review and update core design principles based on this guideline to ensure continuous improvement.

Core Principle 1: Clear, Concise and Relevant Objectives and Goals

Emerging	Developing	Proficient	Best Practice/Advanced
Goals and objectives lack clarity, alignment, and action-oriented language. They are vague, do not define measurable success, and lack structured criteria.	Some alignment with priorities is present, but goals and objectives are not fully aspirational, specific, or measurable. Elements of best practice criteria may be missing.	Goals and objectives are well-aligned, measurable, achievable, and use strong action-oriented language. Best practice criteria (SMART, PACT, HARD) are effectively applied.	Goals and objectives are fully aligned, inspiring, strategic, and well-structured. They drive action, ensure broad impact, and fully integrate best practice criteria.

Core Principle 2: Fit-for-Purpose Evaluation Approaches and Methodologies

Emerging	Developing	Proficient	Best Practice/Advanced
The methods are limited, and data collection is inconsistent. Limited findings that are not reviewed or shared. There is no clear framework and little to no stakeholder involvement. E.g. Evaluation of participants (or one stakeholder) are done measuring outputs (e.g. no. of people attending, bookings made, etc.	Basic use of evaluation methods with minimal analysis. Some findings inform decisions but lack structured implementation. Uses existing frameworks with limited adaptation and resources. Limited stakeholder engagement and internal sharing. E.g. Evaluation approaches may include only one of the following: pre, during and post assessments of participants.	Uses both qualitative and quantitative methods with some interpretation. Findings guide periodic improvements. Adapts frameworks with adequate resources for systematic evaluation. Stakeholders provide input, and findings are shared with key audiences.	Fully integrates mixed methods of evaluation with rigorous analysis e.g., qualitative and quantitative measures of success, observations, interviews, case studies, observations that measure output, outcomes and impact. Findings drive strategic planning and continuous innovation. Blends customised and existing frameworks with strong resource support. Strong co-design with all stakeholders and widespread dissemination of findings. Goals and objectives are aligned with evaluation.

Core Principle 3: Capacity and Capability

Emerging	Developing	Proficient	Best Practice/Advanced
Team skills (e.g. via a skills matrix) and resource needs (e.g. via a resource audit) are not identified nor assessed.	Team skills and resource needs are ad-hoc and inform decisions but lack structured implementation and are often highly responsive rather than planned.	Team skills and resource needs are planned for and adequate. They are systematically assessed, and findings guide periodic improvements.	Team skills and resource needs are regularly audited, and this informs timely and strategic planning and implementation. Customised and existing frameworks ensure strong resource support and drives continuous innovation.

Core Principle 4: Scalability and Sustainability

Emerging	Developing	Proficient	Best Practice/Advanced
No long-term planning, scalability not considered. Complex program structures, difficult to replicate, high resource dependency. Minimal stakeholder engagement, externally driven initiatives. Reliant on a single funding source, no formal partnerships. No clear leadership, rigid or disorganised governance. No evaluation framework, limited response to feedback.	Some sustainability planning, but scalability remains secondary. Some program flexibility but requires significant adaptation to new contexts. Some co-design efforts, but limited community leadership Some partnerships, limited diversification of funding streams. Emerging leadership, structure evolving but inconsistent. Basic evaluation but lacks systematic adaptation to findings.	Sustainability and scalability embedded in program goals and processes. Modular program design with clear documentation for replication. Active community involvement, local leadership emerging. Multi-sector collaborations and diverse funding sources in place. Defined leadership with structured governance balancing flexibility and stability. Continuous assessment and reflection inform iterative improvements.	Designed for sustainability, scalability, and adaptability with clear evaluation frameworks. Simple, scalable program structures with digital integration and adaptable frameworks. Fully co-designed with strong local ownership, leadership, and governance structures. Strong partnerships across sectors, diversified revenue streams, and ongoing financial sustainability planning. Visionary leadership with a mix of centralised strategy and decentralised local ownership, fostering innovation and long-term growth. Embedded reflection and evaluation processes and way of working with real-time adaptability, using stakeholder feedback and data to inform decision-making and refine and expand impact.

Core Principle 5: Strategic Alliances – Collaborations and Partnerships

Emerging	Developing	Proficient	Best Practice/Advanced
Limited collaboration, unclear goals, and low-quality outcomes. Short-term focus with no sustainability planning. Partnerships operate independently with minimal resource-sharing. No governance structures. Static partnerships with limited communication and weak trust. No adaptation to changing needs.	Some alignment with shared goals, but inconsistent quality and impact. Limited long-term planning. Some collaboration and shared resources, but decision-making is unclear. Some communication and trust, but responsiveness to change is slow.	Strong collaboration with high standards, shared strategic goals, and a focus on long-term sustainability. Structured governance, balanced resource-sharing, and clear roles ensuring effective collaboration. Regular communication and evaluations guide improvements and program evolution.	Fully integrated, excellence-driven approach with deep strategic alignment, long-term impact, and continuous improvement. Fully embedded partnerships leveraging unique strengths, with shared governance ensuring sustainability and equitable decision-making. Highly adaptive, transparent partnerships with structured communication, deep trust, and ongoing responsiveness to community needs.

Core Principle 6: Inclusivity and Accessibility

Emerging	Developing	Proficient	Best Practice/Advanced
Programs have financial, geographic, and logistical barriers that limit access. Inclusion is an afterthought; diversity efforts focus only on increasing access. Programs are designed without community input; engagement is top-down. Limited acknowledgment of Indigenous knowledge; programs focus solely on Western science. Few or no diverse role models in STEM engagement programs.	Some efforts to reduce barriers (e.g., scholarships, limited travel support). Some efforts to reduce barriers (e.g., scholarships, limited travel support). Some efforts to understand and address participation gaps but limited systemic change. Some consultation with communities but limited collaboration. Some awareness of Indigenous perspectives but minimal integration into programs. Some representation, but not systematically integrated into program design.	Programs address multiple barriers (costs, transport, timing, di Programs address multiple barriers (costs, transport, timing, disability access). Uses audience research (e.g., Science Capital assessments) to shape program goals and outcomes. Co-design approaches involve communities in planning and delivery. Actively incorporates Indigenous knowledge systems using available frameworks (e.g., 8-Ways, ACDS Guide). Intentional efforts to include diverse facilitators and role models, all-ability access).	Programs are designed with accessibility in mind from the start, removing systemic barriers and ensuring Programs are designed with accessibility in mind from the start, removing systemic barriers and ensuring broad participation. Co-designs programs with underrepresented groups, ensuring full inclusion, belonging, and systemic change in engagement approaches. Programs are fully co-designed and co-delivered with communities, fostering ownership, trust, and sustainability. Fully integrates Indigenous knowledge through co-design with First Nations communities, ensuring meaningful participation and ownership. Diverse role models are central to the program, reflecting the participants' backgrounds and inspiring future STEM leaders. broad participation.

6.2 Assessing Science Engagement Principles

This set of guidelines corresponds to the final seven best practice principles, which emphasise effective science engagement principles. These approaches ensure that participants not only learn the "what" of science but also the "how" and "why," creating a holistic and impactful educational experience.

How to Use These Guidelines:

1. **Self-Assess**: Rate your current science engagement goals and objectives across each category.
2. **Identify Gaps**: Look for areas where improvement is needed.
3. **Refine and Improve**: Apply best practice principles to strengthen your engagement strategies.
4. **Track Progress**: Regularly review and update goals and objectives based on this guideline to ensure continuous improvement.

Best Practice Science Engagement Principle 1: Incorporate Inquiry-Based Learning Approaches

Emerging	Developing	Proficient	Best Practice/Advanced
No clear Inquiry-Based Learning framework used. Learning is mostly directive, learning outcomes are not present and there is little scaffolding, for inquiry, emphasis on critical thinking or teamwork.	An Inquiry-Based Learning framework is referenced or informs practice but is not fully implemented. Some participant input is encouraged, but the facilitator still guides most of the learning and makes the majority of key decisions.	Participants are actively engaged in inquiry, with opportunities to ask and answer their own questions. Participants often determine their own methods and strategies with facilitator support. Participants are actively engaged in inquiry, with opportunities to ask and answer their own questions.	Multiple Inquiry-Based Learning frameworks are integrated and applied, adapting strategies to maximize engagement based on audience needs and capabilities. Participants take ownership of their learning, leading inquiries, note booking their process and discoveries and/or designing investigations. Participants have high levels of autonomy in designing and conducting their inquiry, demonstrating agency and responsibility. Scaffolding is strategically and thoughtfully implemented and of high scientific integrity, allowing

Assessment is instructor driven.	Some collaboration occurs, but teamwork is not structured or emphasized. Some formative assessment of the participant occurs, but participant self-assessment and reflection is limited.	Participants often determine their own methods and strategies with facilitator support and engage in critical thinking and reflection throughout the inquiry process. Participants regularly engage in structured collaboration, refining ideas through peer discussions. Participant assessment includes self-reflection, peer feedback, and facilitator evaluation.	participants to develop independence and meaningful knowledge while maintaining confidence and engagement. Participants work in diverse teams, engaging in dynamic discussions and co-constructing knowledge. Deep critical reflection is embedded, encouraging participants to apply knowledge to varied and novel situations on an ongoing basis. Participants actively and regularly engage in self-assessment and peer evaluation throughout and at all stages, using feedback to refine their inquiry process.

Best Practice Science Engagement Principle 2: Hands-on Experiential Learning – Investigations and Experiments

Emerging	Developing	Proficient	Best Practice/Advanced
No investigations, experiments or hands-on activities occur. Concepts are explained before participants engage in activities.	Investigations, experiments or hands-on activities occur, but engagement with processes, techniques and design is limited and explanations often precede exploration.	Investigations, experiments or hands-on activities occur and participants engage in hands-on activities before receiving explanations, fostering personal discovery.	Dynamic and relevant Investigations, experiments and hands-on activities occur. Participants consistently explore concepts first, leading to deep, self-directed understanding before any explanations are given.

Best Practice Science Engagement Principle 3: Engage Relatable Scientists

Emerging	Developing	Proficient	Best Practice/Advanced
No relatable scientists or STEM professionals are engaged	A relatable scientist may be asked to assist, but their contribution lacks potential depth.	At least one relatable scientist assists in the design, delivery and assessment of the engagement.	Multiple relatable scientists are meaningfully engaged in the co-design, delivery and assessment of the program. The scientist's connection with the program and participants has opportunities for longevity and growth.

Best Practice Science Engagement Principle 4: Influence the Influencers

Emerging	Developing	Proficient	Best Practice/Advanced
External influencers may be included but on a superficial or one-off participation level	External influencers actively participate and receive some type of STEM resources or training.	External influencers actively participate alongside the target audience, receive simple, accessible resources and training.	External influencers are engaged through the design, delivery and assessment phases. They actively and enthusiastically participate alongside target audience often. They receive simple, accessible resources and training to empower their own beliefs and increase their own knowledge of science.

Best Practice Science Engagement Principle 5: Utilise Informal Learning Places and Programs

Emerging	Developing	Proficient	Best Practice/Advanced
Little to no use of informal science settings, places or programs; connections are incidental or missing. Programs do not spark curiosity or excitement; no follow-up to sustain engagement. Access and inclusion are not considered; programs may exclude marginalised groups.	Some informal learning spaces or programs are used, but not consistently or strategically. Some situational interest is created (e.g. through demos), but limited personalisation or sustained learning. Some inclusive elements are present (e.g. diverse venues or online options), but not consistently embedded.	A variety of informal science venues or programs are used purposefully; some partnerships exist to support learning goals. Engagement is interactive and relevant, with follow-up opportunities such as challenges, home activities, or personal pathways. Programs are accessible and inclusive, with efforts to involve underrepresented groups and respond to cultural needs.	Informal science learning environments are deeply embedded into the strategy; partnerships are strong, sustained, and aligned to mutual goals. Experiences are highly engaging and relevant; they spark awe. Long-term interest is supported through tailored pathways, reflection, mentorship, and/or deep personal connection. Programs are co-designed with diverse communities, integrate Indigenous knowledge, and prioritise cultural relevance and belonging in STEM.

Best Practice Science Engagement Principle 6: Connecting with Formal Education – Creating the 'Third Space'

Emerging	Developing	Proficient	Best Practice/Advanced
Learning is disconnected from real-world contexts and curriculum. No teachers or schools are engaged.	Some real-world examples are introduced, but not deeply integrated. Teachers or schools are included, but not meaningfully engaged. There are limited opportunities for teachers to expand their own science teaching practice.	Participants explore real-world applications of their learning but may only focus on one location or context. Teachers or schools are engaged at key times and appropriate ways so that they can meaningfully contribute. Teachers benefit by learning new skills that improve their teaching.	Participants actively apply their learning across contexts, locations and from local to global scales, fostering meaningful impact. Multiple teachers and school leaders are meaningfully engaged in the co-design, delivery and assessment of the program. Teachers are able to inform and improve their own practice, increase their confidence and enrich their own science teaching.

Best Practice Science Engagement Principle 7: Leverage Local Knowledge, Contexts and Resources

Emerging	Developing	Proficient	Best Practice/Advanced
No community asset mapping or community vision articulated. Limited community member involvement, including First Nations community.	A community asset map and/or community vision are created but lack depth. Community members are involved. Consultations with local First Nations Traditional Owners occur in a culturally respectful, safe and meaningful manner.	A detailed and adaptable community asset map and community vision and plan exist. Community members from a range of organisations and demographics are involved. Local First Nations knowledge systems are recognised as rich and valuable assets and are appropriately embedded into programs. This comes from a place of respect and meaningful consultation with Traditional Custodians.	A detailed and adaptable community asset map exists and is regularly updated. A community vision and plan are flourishing. Community members are active partners in the co-design and delivery and can mobilise and leverage external resources. Local First Nations knowledge systems are recognised as rich and valuable assets and are 'Country' is respectfully and meaningfully woven into the program, not an add-on'. Respectful and meaningful consultation with local Traditional Custodians has occurred and is ongoing.

7.0 Conclusions and Key Recommendations

7.1 Conclusions

This report was commissioned to address the need for clearer, evidence-based guidance in the design, delivery, and evaluation of community science engagement programs in Queensland. With increasing investment in such initiatives by government, industry and educational institutions, it is essential that programs are underpinned by best practice principles that ensure they are effective, inclusive, and sustainable. Drawing on extensive national and international literature, this review presents a set of 13 best practice principles – six core design principles and seven science engagement principles – that provide a clear and practical framework for practitioners and decision-makers alike.

A central insight from this work is the importance of science capital – a construct that integrates scientific knowledge, attitudes, experiences, and social networks that influence an individual's relationship with science, including study and career aspirations. As explored in Chapter 3.2, science capital provides both a rationale and framework for community science engagement. Programs that successfully enhance science capital are more likely to promote sustained interest in science, broaden participation in STEM, and contribute to more equitable outcomes, particularly for underrepresented groups.

The six core *design* principles articulated in Chapter 4 focus on foundational elements that underpin successful community engagement programs, in a general sense – they are non-discipline-specific and underpin the success of *any* community engagement program. The six core design principles are:

- Setting clear and relevant goals and objectives
- Employing fit-for-purpose evaluation methodologies
- Building capabilities and capacity
- Planning for sustainability and scalability
- Establishing strategic alliances, and
- Ensuring inclusivity and accessibility

These principles are interdependent – for example, setting clear goals and objectives facilitate meaningful evaluation; collaborations and partnerships can strengthen capacity, capabilities and sustainability; and inclusive design impacts scalability and the ability to connect with diverse and underrepresented communities.

Chapter 5 presents the seven *science engagement* principles, which reflect both educational best practices and the social realities specifically relating to effective community engagement with science. The seven science engagement principles are:

- Incorporating inquiry-based learning approaches
- Adopting hands-on experiential learning
- Engage relatable scientists
- Influencing the influencers of youth choice
- Utilising informal learning places and programs
- Connecting with formal education sector, and
- Leveraging local assets

Each principle supports deeper, more personalised engagement with science and aims to improve the perceived relevance and accessibility of science in everyday life.

This report also explores the value of culturally responsive approaches, especially in engaging First Nations communities. Drawing on concepts such as *Country*, First Nations science capital, and Indigenous ways of learning, the report highlights how programs can embed First Nations perspectives respectfully and meaningfully. Rather than treating First Nations cultural knowledge and perspectives as peripheral challenges to be addressed, these approaches recognise them as valuable assets to be used for advantage to enrich and strengthen programs.

In summary, this document offers a comprehensive resource for practitioners, educators, policymakers and funders involved in, and contributing to, community science engagement. It can be used to design new programs, evaluate existing initiatives, guide funding decisions, and promote cross-sector partnerships. While every community and context are different, the principles outlined here are adaptable and provide a shared understanding and set of standards for excellence in community science engagement.

Future implementation of these principles – supported by the assessment guidelines in Chapter 6 – has the potential to increase the reach, relevance, and impact of community science engagement in Queensland and beyond. In doing so, these programs can help cultivate a scientifically literate, curious and empowered public, better prepared to navigate and contribute to the scientific challenges and opportunities of the 21st century.

7.2 Recommendations

The recommendations below are intended to guide the design, delivery, evaluation, and refinement of community science engagement programs across Queensland and beyond.

These recommendations are structured in alignment with the two overarching themes outlined in this report: *Core Program Design Principles* (Chapter 4) and *Science Engagement Principles* (Chapter 5). Collectively, they provide practical guidance for designing new programs and strengthening existing initiatives.

7.2.1 Core program design recommendations

RECOMMENDATION 1: ***Set clear goals, objectives and intended outcomes appropriate for the target audience with practical means of evaluating program effectiveness.***

Establishing well-articulated goals and measurable objectives from the outset provides the foundation for successful and accountable community science engagement programs. Drawing from *Core Design Principles* 1 and 2, program designers are encouraged to articulate ambitious, long-term goals, supported by achievable and measurable short- and medium-term objectives.

A program logic model should inform the development process (Section 4.2.3), linking desired outcomes to specific engagement activities. Effective evaluation should be multifaceted, employing both quantitative methods (e.g., surveys, pre/post assessments) and qualitative approaches (e.g., interviews, focus groups, case studies) to capture changes in participant attitudes, knowledge, confidence, and behaviours. Where possible and appropriate, programs should adapt existing (validated) evaluation tools and approaches.

Evaluating outcomes for participants is essential, however, program leaders should also consider program evaluations for other stakeholders including facilitators, organisers, partners and funders. Pre-, during- and post-program evaluations should be carried out supporting continuous improvement and the development of an evidence base for future program development. Where possible, longitudinal tracking can help measure sustained impact over time, especially in relation to participant aspirations and career trajectories.

RECOMMENDATION 2: *Develop strategic alliances to build program capacity, capabilities, and facilitate ongoing sustainability.*

To ensure long-term success, community science engagement programs should be built on a foundation of synergistic collaboration and the creation of new value. *Core Design Principles 3, 4 and 5* emphasise the importance of identifying and leveraging complementary strengths through the creation of strategic alliances with schools, local organisations, researchers, government, industry, and community groups.

Programs that prioritise collaborative design and delivery can draw on a broader base of expertise and resources, reducing duplication and enhancing relevance. Strategic alliances should be developed with a view to shared ownership, drawing on the concept of 'collaborative advantage' to increase reach, sustainability and impact.

A planned approach to capability-building, such as conducting resource audits and mapping skills across partners, can help identify gaps and opportunities. Programs should be designed with long-term sustainability in mind from the outset, considering not just how to launch or pilot activities, but how to maintain and scale them in a way that ensures continued relevance, value and impact.

RECOMMENDATION 3: *Embed inclusivity and accessibility in all aspects of program design and delivery.*

Addressing inclusivity and accessibility is both an ethical obligation and a practical necessity. *Core Design Principle 6* emphasises the need to recognise and address the diverse needs, values, and lived experiences of different audiences – broadening both civic scientific literacy and the STEM pipeline.

Programs should be informed by an understanding of the science capital of participants and subsequently guided by culturally responsive practices that resonate with participant cultural, social and geographic contexts. Co-design processes that involve community members from the beginning will enhance cultural responsiveness and relevance.

Staff capabilities should also reflect a commitment to equity, including training in cultural competency and sensitivity and a consideration of factors such as disability access, gender equity, socio-economic diversity, and intergenerational participation.

7.2.2 Science Engagement Recommendations

When developing science engagement approaches, it is important to consider how the program activities align with the four components and eight dimensions of science capital. Programs should be designed to affect:

- what participants know about science – including science content and the nature of science and scientific inquiry
- what they think about science – their attitudes and aspirations
- how they interact with science – particularly outside formal educations settings, and
- how they are connected to people who influence their views about science.

Recommendation 4: ***Incorporate inquiry-based learning and hands-on experiential approaches addressing both science understandings and scientific investigative skills.***

Effective science engagement should reflect how people actually learn – through doing, questioning, exploring and reflecting. *Science Engagement Principles 1 and 2* highlight the importance of inquiry-based and hands-on learning that builds both content knowledge and scientific process skills.

Programs should adopt established, evidence-informed and readily implemented models of inquiry-based learning (IBL) and experiential education, scaffolding learning experiences to be developmentally appropriate and culturally relevant. These approaches not only deepen scientific understanding but also positively affect curiosity, resilience, and confidence.

Importantly, such engagement should not focus solely on scientific literacy but also enhance the social dimensions of science capital – such as collaborative problem-solving, valuing diverse perspectives, and understanding the role of science in everyday life.

Recommendation 5: ***Engage key influencers of youth choice including parents, teacher, and friends, as well relatable and culturally relevant scientists and STEM role models.***

Science engagement does not happen in isolation. As *Science Engagement Principles 3 and 4* affirm, the attitudes and aspirations of young people are shaped significantly by those around them – including parents, teachers, friends, and trusted figures in their communities.

Programs should deliberately seek to engage these key influencers, both directly and indirectly. This might include parent-inclusive events, teacher professional development, peer mentoring initiatives, or partnerships with local scientists who reflect the cultural and demographic backgrounds of the target audience.

Relatable and authentic STEM role models, particularly those from underrepresented groups, can be powerful in shifting perceptions about who can participate in science, and what science pathways look like.

Recommendation 6: ***Connect with educators and STEM engagement professionals in formal and informal learning environments.***

Connecting with professionals in both formal (schools) and informal (museums, libraries, maker spaces) education settings is critical for embedding science engagement more deeply in the community. *Science Engagement Principles 5 and 6* suggest that successful programs often emerge through such cross-sector collaboration.

By working with educators, programs can better align with curricula, extend learning beyond the classroom, and support continuity and sustainability of engagement. STEM professionals can offer real-world relevance and mentorship, helping to bridge gaps between school science and community understanding.

These partnerships also support professional learning for educators and ensure program delivery is pedagogically sound and age appropriate.

RECOMMENDATION 7: *Ensure locally relevant contexts, resources and people are central to program design and delivery.*

Grounding community science engagement in local settings ensures that programs are relevant and inclusive, as well as contributing to program sustainability. *Science Engagement Principle 7* underscores the value of working with community knowledge, leaders, cultures and traditions, recognising that meaningful engagement must reflect participants' lived realities. This principle is further strengthened by an asset-based community development approach, which reframes how communities can be engaged – not through a deficit approach (what they lack), but through the strengths they already hold.

This engagement approach highlights local people, cultural traditions, organisations, infrastructure and natural geographical resources as critical assets that can drive science engagement. When programs are co-developed around these existing assets, they are not only more effective, but they also affirm and validate local expertise, creating a sense of ownership and empowerment. This also transforms engagement from a top-down dissemination model to a participatory, place-based exchange of knowledge and experience. In this way, local assets become the foundation upon which enduring science engagement is built.

These recommendations offer a flexible, evidence-based framework for designing and delivering high-quality, inclusive, and impactful community science engagement programs. Rather than serving as a one-size-fits-all checklist, they are intended to be adapted to the specific needs, contexts, and aspirations of diverse communities and programs across Queensland and beyond.

When embedded thoughtfully, these best-practice approaches support co-designed, culturally responsive, and sustained engagement. Applied consistently, they can enhance science capital, strengthen community relationships with science, and ensure that programs remain adaptable, meaningful, and sustainable.

8.0 Bibliography

AAS. (2019). *Women in STEM Decadal Plan*. Australian Academy of Science. https://www.science.org.au/support/analysis/decadal-plans-science/women-in-stem-decadal-plan

Abdulwahed, M., & Nagy, Z. K. (2009). Applying Kolb's experiential learning cycle for laboratory education. *Journal of engineering education*, *98*(3), 283-294.

Abes, E. S., Jackson, G., & Jones, S. R. (2002). Factors that motivate and deter faculty use of service-learning. *Michigan Journal of community service learning*, *9*(1).

Abourashed, A., Doornekamp, L., Escartin, S., Koenraadt, C. J. M., Schrama, M., Wagener, M., Bartumeus, F., & Van Gorp, E. C. M. (2021). The Potential Role of School Citizen Science Programs in Infectious Disease Surveillance: A Critical Review. *International Journal of Environmental Research and Public Health*, *18*(13), 7019. https://doi.org/10.3390/ijerph18137019

ACARA. (2025). *Australian Curriculum: Science*. Retrieved 15/02/2025 from https://v9.australiancurriculum.edu.au/curriculum-information/understand-this-learning-area/science

ACER. (2018). *PISA 2018 - Reporting Australia’s Results Volume I Student Performance*. https://research.acer.edu.au/cgi/viewcontent.cgi?article=1035&context=ozpisa

Aero. (2024). Scaffold Practice - Guide student learning and gradually remove scaffolds. https://www.edresearch.edu.au/sites/default/files/2024-11/AERO-practice-guide-scaffold-practice-aa.pdf

Agnew, S., Kopke, K., Power, O.-P., Troya, M. D. C., & Dozier, A. (2022). Transdisciplinary research: Can citizen science support effective decision-making for coastal infrastructure management? *Frontiers in Marine Science*, *9*, 809284.

Ah Chee, J., Bennett, R., Cirkony, C., Coutts, K., Fairbrother, L., Gunning, T., Raven, T., Sambono, J., Singh, L.-J., & Uink, B., Ziebell, A. . (2024). *A guide for curriculum development: First Nations Australians’ Science*. https://www.acds.edu.au/wp-content/uploads/A-guide-for-curriculum-development-First-Nations-Australians-Science-Online-v2.pdf

Akins, E. (2015). *The impact of funding on nonprofit organizations' sustainability* Capella University].

Alkan, F. (2016). Experiential Learning: Its Effects on Achievement and Scientific Process Skills. *Journal of Turkish Science Education*, *13*(2), 15-26.

Allen, S., Campbell, P. B., Dierking, L. D., Flagg, B. N., Garibay, C., Korn, R., Silverstein, G., & Ucko, D. (2008). *Framework for evaluating impacts of informal science education projects* (National Science Foundation Workshop, Issue. https://informalscience.org/wp-content/uploads/2022/05/Eval_Framework.pdf

Allen-Ramdial, S.-A. A., & Campbell, A. G. (2014). Reimagining the Pipeline: Advancing STEM Diversity, Persistence, and Success. *BioScience*, *64*(7), 612-618. https://doi.org/10.1093/biosci/biu076

Alsaleh, N. J. (2020). Teaching Critical Thinking Skills: Literature Review. *Turkish Online Journal of Educational Technology-TOJET*, *19*(1), 21-39.

Anderson, A., Kollmann, E. K., Beyer, M., Weitzman, O., Bequette, M., Haupt, G., & Velázquez, H. (2021). Design strategies for hands-on activities to increase interest, relevance, and self-efficacy in chemistry. *Journal of Chemical Education*, *98*(6), 1841-1851.

Anderson, A. A., Myers, T. A., Maibach, E. W., Cullen, H., Gandy, J., Witte, J., Stenhouse, N., & Leiserowitz, A. (2013). If they like you, they learn from you: How a brief weathercaster-delivered climate education segment is moderated by viewer evaluations of the weathercaster. *Weather, Climate, and Society*, *5*(4), 367-377.

Anderson, K. J., & Minke, K. M. (2007). Parent involvement in education: Toward an understanding of parents' decision making. *The Journal of educational research*, *100*(5), 311-323.

Anderson, L., Grove, J., Williams, G., & Grand, A. (2019). *Evaluating community engagement*.

Andrews, E., Weaver, A., Hanley, D., Shamatha, J., & Melton, G. (2005). Scientists and public outreach: Participation, motivations, and impediments [Article]. *Journal of Geoscience Education*, *53*(3), 281-293. https://doi.org/10.5408/1089-9995-53.3.281

Antink-Meyer, A., Brown, M., & Wolfe, A. (2023). The Scientific Curiosity of Preservice Elementary Teachers and Confidence for Teaching Specific Science Topics [Article]. *Journal of Science Teacher Education*, *34*(8), 883-902. https://doi.org/10.1080/1046560X.2023.2168858

Appleton, K., & Kindt, I. (1999). Why teach primary science? Influences on beginning teachers' practices. *International Journal of Science Education*, *21*(2), 155-168.

Archer, L., Dawson, E., DeWitt, J., Godec, S., King, H., Mau, A., Effrosyni, N., & Seakins, A. (2016). *Science Capital Made Claer*. https://www.stem.org.uk/sites/default/files/pages/downloads/Science-Capital-Made-Clear.pdf

Archer, L., Dawson, E., Dewitt, J., Seakins, A., & Wong, B. (2015). “Science capital”: A conceptual, methodological, and empirical argument for extending bourdieusian notions of capital beyond the arts. *Journal of Research in Science Teaching*, *52*(7), 922-948. https://doi.org/10.1002/tea.21227

Archer, L., & Dewitt, J. (2015). Science Aspirations and Gender Identity: Lessons from the ASPIRES Project. In (pp. 89-102). Springer Netherlands. https://doi.org/10.1007/978-94-007-7793-4_6

Archer, L., DeWitt, J., Godec, S., Henderson, M., Holmegaard, H., Liu, Q., Macleod, E., Mendick, H., Moote, J., & Watson, E. (2023). ASPIRES3 Main Report: Young People's STEM Trajectories, Age 10-22.

Archer, L., DeWitt, J., & King, H. (2018). Improving science participation: Five evidence-based messages for policy-makers and funders. https://discovery.ucl.ac.uk/id/eprint/10080168/1/improving-science-participation-policy-overview.pdf

Archer, L., DeWitt, J., Osborne, J., Dillon, J., Willis, B., & Wong, B. (2012a). “Balancing acts'': Elementary school girls' negotiations of femininity, achievement, and science. *Science education*, *96*(6), 967-989.

Archer, L., DeWitt, J., Osborne, J., Dillon, J., Willis, B., & Wong, B. (2012b). Science aspirations, capital, and family habitus: How families shape children’s engagement and identification with science. *American educational research journal*, *49*(5), 881-908.

Archer, L., DeWitt, J., & Willis, B. (2014). Adolescent boys' science aspirations: Masculinity, capital, and power. *Journal of Research in Science Teaching*, *51*(1), 1-30.

Archer, L., Moote, J., Macleod, E., Francis, B., & DeWitt, J. (2020). *ASPIRES 2: Young people's science and career aspirations, age 10–19*. U. I. o. Education.

Arksey, H., & O'malley, L. (2005). Scoping studies: towards a methodological framework. *International journal of social research methodology*, *8*(1), 19-32.

Arnold, J. C., Kremer, K., & Mayer, J. (2014). Understanding Students' Experiments—What kind of support do they need in inquiry tasks? *International Journal of Science Education*, *36*(16), 2719-2749. https://doi.org/10.1080/09500693.2014.930209

Aulia, E., Poedjiastoeti, S., & Agustini, R. (2018). The effectiveness of guided inquiry-based learning material on students’ science literacy skills. *Journal of Physics: Conference Series*, *947*(1), 012049.

Ayalon, H., & Yuchtman-Yaar, E. (1989). Educational opportunities and occupational aspirations: A two-dimensional approach. *Sociology of education*, 208-219.

Ballard, H. L., Lindell, A. J., & Jadallah, C. C. (2024). Environmental education outcomes of community and citizen science: a systematic review of empirical research [Article]. *Environmental Education Research*, *30*(6), 1007-1040. https://doi.org/10.1080/13504622.2024.2348702

Balta, N. (2016). The Effect of 7E Learning Cycle on Learning in Science Teaching: A meta-Analysis Study. *European Journal of Educational Research*, *5*, 61-72. https://doi.org/10.12973/eu-jer.5.2.61

Banerjee, M., Harrell, Z. A., & Johnson, D. J. (2011). Racial/ethnic socialization and parental involvement in education as predictors of cognitive ability and achievement in African American children. *Journal of youth and adolescence*, *40*, 595-605.

Barnes, E. C., Jamie, I. M., Vemulpad, S. R., Yaegl Community, E., Breckenridge, D., Froud, A. E., Harrington, D. G., Packer, J. M., Prenzler, P. D., Bedgood, D. R., Jr., & Jamie, J. F. (2022). National Indigenous Science Education Program (NISEP): Outreach Strategies That Facilitate Inclusion. *Journal of Chemical Education*, *99*(1), 245-251. https://doi.org/10.1021/acs.jchemed.1c00393

Barrow, L. (2006). A Brief History of Inquiry: From Dewey to Standards. *Journal of Science Teacher Education*, *17*, 265-278. https://doi.org/10.1007/s10972-006-9008-5

Barthel, C. F. (2020). *Exploring the relationship between scientists' perspectives on learning and engagement in outreach* Oregan State University].

Bathgate, M. E., Schunn, C. D., & Correnti, R. (2014). Children's motivation toward science across contexts, manner of interaction, and topic. *Science education*, *98*(2), 189-215.

Bauer, M., Allum, N., & Miller, S. (2007). What Can We Learn from 25 Years of PUS Survey Research? Liberating and Expanding the Agenda. *Public Understanding of Science*, *16*. https://doi.org/10.1177/0963662506071287

Bayram, Z., Oskay, Ö. Ö., Erdem, E., Özgür, S. D., & Şen, Ş. (2013). Effect of inquiry based learning method on students' motivation. *Procedia-Social and Behavioral Sciences*, *106*, 988-996.

Bell, P., Lewenstein, B., Shouse, A., & Feder, M. (2009). *Learning Science in Informal Environments: People, Places, and Pursuits* (Vol. 43).

Berg, T. B., Achiam, M., Poulsen, K. M., Sanderhoff, L. B., & Tottrup, A. P. (2021). The Role and Value of Out-of-School Environments in Science Education for 21st Century Skills. *Frontiers in Education*, *6*(674541). https://doi.org/10.3389/feduc.2021.674541

Bergman, J., Williams, L. A., & Harvey-Smith, L. (2023). *Pathway to Diversity in STEM Review*. https://www.industry.gov.au/sites/default/files/2024-02/pathway-to-diversity-in-stem-review-final-report.pdf

Besley, J., Dudo, A., & Yuan, S. (2018). Scientists' views about communication objectives. *Public Understanding of Science*, *27*(6), 708-730. https://doi.org/10.1177/0963662517728478

Besley, J., Dudo, A., Yuan, S., & Lawrence, F. (2018). Understanding Scientists' Willingness to Engage. *Science Communication*, *40*(5), 559-590. https://doi.org/10.1177/1075547018786561

Besley, J. C., Dudo, A., & Storksdieck, M. (2015). Scientists' views about communication training. *Journal of Research in Science Teaching*, *52*(2), 199-220. https://doi.org/10.1002/tea.21186

Besley, J. C., & Nisbet, M. (2011). How scientists view the public, the media and the political process. *Public Understanding of Science*, *22*(6), 644-659.

Besley, J. C., & Tanner, A. H. (2011). What Science Communication Scholars Think About Training Scientists to Communicate. *Science Communication*, *33*(2), 239-263. https://doi.org/10.1177/1075547010386972

Bevan, B., Calabrese Barton, A., & Garibay, C. (2018). *Broadening Perspectives on Broadening Participation in STEM: Critical Perspectives on the Role of Science Engagement*.

Bevan, B., Calabrese Barton, A., & Garibay, C. (2020). Broadening Perspectives on Broadening Participation: Professional Learning Tools for More Expansive and Equitable Science Communication. *Frontiers in Communication*, *5*. https://doi.org/10.3389/fcomm.2020.00052

Bonney, R., Ballard, H., Jordan, R., McCallie, E., Phillips, T., Shirk, J., & Wilderman, C. C. (2009). *Public Participation in Scientific Research: Defining the Field and Assessing Its Potential for Informal Science Education. A CAISE Inquiry Group Report*.

Bonney, R., Cooper, C. B., Dickinson, J., Kelling, S., Phillips, T., Rosenberg, K. V., & Shirk, J. (2009). Citizen Science: A Developing Tool for Expanding Science Knowledge and Scientific Literacy. *BioScience*, *59*(11), 977-984. https://doi.org/10.1525/bio.2009.59.11.9

Bonney, R., Phillips, T. B., Ballard, H. L., & Enck, J. W. (2016). Can citizen science enhance public understanding of science? *Public Understanding of Science*, *25*(1), 2-16. https://doi.org/10.1177/0963662515607406

Bonney, R., Shirk, J. L., Phillips, T. B., Wiggins, A., Ballard, H. L., Miller-Rushing, A. J., & Parrish, J. K. (2014). Next steps for citizen science. *Science*, *343*(6178), 1436-1437.

Bordenstein, S. R., Brothers, C., Wolfe, G., Bahr, M., Minckley, R. L., Clark, M. E., Wernegreen, J. J., Bordenstein, S. R., Reznikoff, W. S., & Werren, J. H. (2010). Using the Wolbachia bacterial symbiont to teach Inquiry-based science: A high school laboratory series. *The american biology Teacher*, *72*(8), 478-483.

Braund, M., & Reiss, M. (2006). Towards a more authentic science curriculum: The contribution of out-of-school learning. *International Journal of Science Education*, *28*(12), 1373-1388.

Brossard, D., & Lewenstein, B. V. (2009). A critical appraisal of models of public understanding of science: Using practice to inform theory. In *Communicating science* (pp. 25-53). Routledge.

Brouwer, S., & Hessels, L. K. (2019). Increasing research impact with citizen science: The influence of recruitment strategies on sample diversity. *Public Understanding of Science*, *28*(5), 606-621.

Brown, P. (2020). *Instructional Sequence Matters - Explore Before Explain*. NSTA Press.

Brown, P. (2024). Activating Learning with Phenomena. *Science and Children*, *61*(5), 9-11. https://doi.org/10.1080/00368148.2024.2386972

Bryson, J. M., Crosby, B. C., & Stone, M. M. (2015). Designing and Implementing Cross-Sector Collaborations: Needed *and* Challenging. *Public Administration Review*, *75*(5), 647-663. https://doi.org/10.1111/puar.12432

Buchanan, S., Harlan, M., Bruce, C., & Edwards, S. (2016). Inquiry based learning models, information literacy, and student engagement: A literature review. *School Libraries Worldwide*, *22*(2), 23-39.

Bybee, R., Taylor, J., Gardner, A., Scotter, P., Carlson, J., Westbrook, A., & Landes, N. (2006). The BSCS 5E Instructional Model: Origins, Effectiveness, and Applications. *BSCS*.

Bybee, R. W. (1997). *Achieving scientific literacy: From purposes to practices*. Heinemann.

Bybee, R. W. (2014). The BSCS 5E instructional model: Personal reflections and contemporary implications. *Science and Children*, *51*(8), 10-13.

CAISE. (2010). *Making Science Matter: Collaborations Between Informal Science Education Organizations and Schools*. https://informalscience.org/research/making-science-matter-collaborations-between-informal-science-education-organizations-and-schools/

Cavalcante, A., & Gonsalves, A. J. (2021). Undergraduate Science Majors' Identity Work in the Context of a Science Outreach Program: Understanding the Role of Science Capital. In O. Levrini, G. Tasquier, T. G. Amin, L. Branchetti, & M. Levin (Eds.), *Engaging with Contemporary Challenges through Science Education Research: Selected papers from the ESERA 2019 Conference* (pp. 173-183). Springer International Publishing. https://doi.org/10.1007/978-3-030-74490-8_14

Chin, C. (1992). The use of discrepant events in teaching and learning science. *Teaching and Learning*, *13*(1), 51-57.

Chin, C., & Brown, D. E. (2000). Learning in Science: A Comparison of Deep and Surface Approaches. *Journal of Research in Science Teaching*, *37*(2), 109-138. https://doi.org/10.1002/(sici)1098-2736(200002)37:2<109::aid-tea3>3.0.co;2-7

Christopherson, E. G., Scheufele, D. A., & Smith, B. (2018). The Civic Science Imperative. *Stanford Social Innovation Review*, *16*(2), 46-52. https://doi.org/10.48558/6K46-1C68

Clark, G., Russell, J., Enyeart, P., Gracia, B., Wessel, A., Jarmoskaite, I., Polioudakis, D., Stuart, Y., Gonzalez, T., Mackrell, A., Rodenbusch, S., Stovall, G. M., Beckham, J. T., Montgomery, M., Tasneem, T., Jones, J., Simmons, S., & Roux, S. (2016). Science Educational Outreach Programs That Benefit Students and Scientists. *PLOS Biology*, *14*(2), e1002368. https://doi.org/10.1371/journal.pbio.1002368

Coker, J. S. (2017). Pedagogy and place in science education. In D. G. Shannon, J. (Ed.), *Interdisciplinary approaches to pedagogy and place-based education: From abstract to the quotidian* (pp. 71-83). Palgrave Macmillan, Cham. https://doi.org/doi.org/10.1007/978-3-319-50621-0_6

Collins, L. W., & Fulton, L. (2017). Promising Practices for Supporting Students with Disabilities through Writing in Science [Article]. *Teaching Exceptional Children*, *49*(3), 194-203. https://doi.org/10.1177/0040059916670629
Cooper, G., Fricker, A., & Gough, A. (2024). Promoting First Nations science capital: reimagining a more inclusive curriculum. *International Journal of Science Education*, 1-14. https://doi.org/10.1080/09500693.2024.2354077
Cooper, G., P., T. D., Vaughan, P., & and Fraser, S. (2022). Associations between Australian students' literacy achievement in early secondary school and senior secondary participation in science: accessing cultural and science capital. *International Journal of Science Education*, *44*(10), 1549-1564. https://doi.org/10.1080/09500693.2022.2086317
Copple, J., Bennett, N., Dudo, A., Moon, W.-K., Newman, T. P., Besley, J., Leavey, N., Lindenfeld, L., & Volpe, C. (2020). Contribution of Training to Scientists' Public Engagement Intentions: A Test of Indirect Relationships Using Parallel Multiple Mediation. *Science Communication*, *42*(4), 508-537. https://doi.org/10.1177/1075547020943594
Council, N. R. (2000). *Inquiry and the National Science Education Standards: A Guide for Teaching and Learning.* The National Academies Press. https://doi.org/10.17226/9596
Council, N. R. (2012). *Equity and diversity in science and engineering education* (A framework for K-12 science education, Issue. https://nap.nationalacademies.org/read/13165/chapter/16
Coventry, V. (1997). *Major influences on career choice: A study conducted on behalf of Scitech Discovery Centre, Perth, Western Australia*.
Crosby, B. C., & Bryson, J. M. (2005). *Leadership for the common good: Tackling public problems in a shared-power world* (Vol. 264). John Wiley & Sons.
CSIRO. (2024). *Durable STEM Education Programs:nEvidence from Diverse Fields*. https://www.csiro.au/-/media/Education-and-Outreach/Impact-Library/Research-reports/Files/Durable-STEM-Education-Programs---Evidence-from-Diverse-Fields.pdf
Cunningham, G., & Mathie, A. (2002). Asset-based community development: An overview. *Coady International Institute. Retrieved February*, *4*, 2009.
Currie, A., & Levy, A. (2018). Why Experiments Matter. *Inquiry*, *62*. https://doi.org/10.1080/0020174X.2018.1533883
Dabney, K. P., Tai, R. H., Almarode, J. T., Miller-Friedmann, J. L., Sonnert, G., Sadler, P. M., & Hazari, Z. (2012). Out-of-school time science activities and their association with career interest in STEM. *International Journal of Science Education, Part B*, *2*(1), 63-79.
Davies, S. R. (2013). Constituting Public Engagement: Meanings and Genealogies of PEST in Two U.K. Studies [Article]. *Science Communication*, *35*(6), 687-707. https://doi.org/10.1177/1075547013478203
Dawson, E. (2014). "Not designed for us": How science museums and science centers socially exclude low-income, minority ethnic groups. *Science education*, *98*(6), 981-1008.
de Jong, T. (2006). Scaffolds for scientific discovery learning. *Handling complexity in learning environments: Theory and research*, 107-128. https://books.google.com.au/books?hl=en&lr=&id=buY4icX3LbAC&oi=fnd&pg=PA107&dq=scaffolding+experimental+design+in+science+&ots=mnLqrNxBV0&sig=O4gKZLZFiceJfB-5ZnOqJ10n_FQ#v=onepage&q=scaffolding%20experimental%20design%20in%20science&f=false
Deci, E. L., & Ryan, R. M. (2000). The" what" and" why" of goal pursuits: Human needs and the self-determination of behavior. *Psychological inquiry*, *11*(4), 227-268.
Denson, C., Austin, C., Hailey, C., & Householder, D. (2015). Benefits of informal learning environments: A focused examination of STEM-based program environments. *Journal of STEM Education*, *16*(1).
DeWitt, J., & Archer, L. (2017). Participation in informal science learning experiences: The rich get richer? *International Journal of Science Education, Part B*, *7*(4), 356-373.

DeWitt, J., Archer, L., & Mau, A. (2016). Dimensions of science capital: exploring its potential for understanding students' science participation. *International Journal of Science Education*, *38*(16), 2431-2449.

DeWitt, J., Archer, L., & Osborne, J. (2014). Science-related aspirations across the primary–secondary divide: Evidence from two surveys in England. *International Journal of Science Education*, *36*(10), 1609-1629.

DeWitt, J., Spela, G., Emma, W., Louise, A., & and Moote, J. (2025). Who participates in informal science learning experiences? Analysis of data from six surveys of a cohort in England from age 10–22 years. *International Journal of Science Education, Part B*, 1-18. https://doi.org/10.1080/21548455.2025.2462798

Dickinson, J. L., Shirk, J., Bonter, D., Bonney, R., Crain, R. L., Martin, J., Phillips, T., & Purcell, K. (2012). The current state of citizen science as a tool for ecological research and public engagement. *Frontiers in Ecology and the Environment*, *10*(6), 291-297.

Doran, G. T. (1981). There's a SMART way to write managements's goals and objectives. *Management review*, *70*(11), 35-36.

Dorsen, J., Carlson, B., & Goodyear, L. (2006). *Connecting informal STEM experiences to career choices: Identifying the pathway*. https://stelar.edc.org/sites/default/files/itestliteraturereview06.pdf

Doucet, F. (2017). What does a culturally sustaining learning climate look like? *Theory Into Practice*, *56*(3), 195-204.

Driel, J. (2014). Professional Learning of Science Teachers. In (pp. 139-157). https://doi.org/10.1007/978-94-007-7281-6_9

Dudo, A., & Besley, J. C. (2016). Scientists' prioritization of communication objectives for public engagement. *PLOS ONE*, *11*(2), e0148867. https://journals.plos.org/plosone/article/file?id=10.1371/journal.pone.0148867&type=printable

Duran, L. B., & Duran, E. (2004). The 5E instructional model: A learning cycle approach for inquiry-based science teaching. *Science Education Review*, *3*(2), 49-58.

Duschl, R. A., & Bybee, R. W. (2014). Planning and carrying out investigations: An entry to learning and to teacher professional development around NGSS science and engineering practices. *International Journal of STEM Education*, *1*, 1-9.

EducationCouncil. (2015). *National STEM School Education Strategy (2016-2026)*. https://www.education.gov.au/australian-curriculum/resources/national-stem-school-education-strategy

Edwards, C. D., Lee, W. C., Knight, D. B., Fletcher, T., Reid, K., & Lewis, R. (2021). Outreach at Scale: Developing a Logic Model to Explore the Organizational Components of the Summer Engineering Experience for Kids Program. *Advances in Engineering Education*, *9*(2), n2.

Eilam, E., Bigger, S. W., Sadler, K., Barry, F., & Bielik, T. (2016). Universities Conducting STEM Outreach: a Conceptual Framework. *Higher Education Quarterly*, *70*(4), 419-448. https://doi.org/10.1111/hequ.12105

Eisenkraft, A. (2003). Expanding the 5E model. *The science teacher*, *70*(6), 56.

Eitzel, M., Cappadonna, J., Santos-Lang, C., Duerr, R., West, S. E., Virapongse, A., Kyba, C., Bowser, A., Cooper, C., & Sforzi, A. (2017). Citizen science terminology matters: Exploring key terms. *Citizen science: Theory and practice*, 1-20.

Ens, E. J., Pert, P., Clarke, P. A., Budden, M., Clubb, L., Doran, B., Douras, C., Gaikwad, J., Gott, B., & Leonard, S. (2015). Indigenous biocultural knowledge in ecosystem science and management: Review and insight from Australia. *Biological Conservation*, *181*, 133-149.

Evans-Agnew, R. A., & Eberhardt, C. (2019). Uniting action research and citizen science: Examining the opportunities for mutual benefit between two movements through a woodsmoke photovoice study. *Action Research*, *17*(3), 357-377.

Falk, J. H., & Dierking, L. D. (2010). School is not where most Americans learn most of their science. *American Scientist*, *98*(6), 486.
Falk, J. H., Storksdieck, M., & Dierking, L. D. (2007). Investigating public science interest and understanding: Evidence for the importance of free-choice learning. *Public Understanding of Science*, *16*(4), 455-469.
Farrell, B., & Medvedeva, M. (2010). *Demographic transformation and the future of museums*. https://knowledge.uchicago.edu/record/1272?v=pdf
Feinstein, N. W., & Meshoulam, D. (2014). Science for what public? Addressing equity in American science museums and science centers. *Journal of Research in Science Teaching*, *51*(3), 368-394.
Fischhoff, B. (2013). The sciences of science communication. *Proceedings of the National Academy of Sciences*, *110*(supplement_3), 14033-14039.
Fisher, G. R., Esparza, D., & Olimpo, J. T. (2019). Place-Based Case Studies: A New Approach to an Effective Teaching Practice. *Journal of Microbiology and Biology Education*, *20*(1), 10.1128/jmbe.v1120i1121.1611. https://doi.org/doi:10.1128/jmbe.v20i1.1611
Fiske, S. T., & Dupree, C. (2014). Gaining trust as well as respect in communicating to motivated audiences about science topics. *Proceedings of the National Academy of Sciences*, 13593-13597. https://doi.org/10.1073/pnas.1317505111
Flick, L. (2000). Cognitive Scaffolding that Fosters Scientific Inquiry in Middle Level Science. *Journal of Science Teacher Education*, *11*, 109-129. https://doi.org/10.1023/A:1009464707968
Frechtling, J., and Sharp, L. . (1997). *The User-Friendly Handbook for Mixed-Method Evaluations*. http://www.nsf.gov/pubs/1997/nsf97153/start.htm
Friedman, D. P. (2008). Public outreach: a scientific imperative. *Journal of Neuroscience*, *28*(46), 11743-11745.
Friesen, S., & Scott, D. (2013). Inquiry-based learning: A review of the research literature. *Alberta Ministry of Education*, *32*, 1-32.
Friesner, J., Colón-Carmona, A., Schnoes, A. M., Stepanova, A., Mason, G. A., Macintosh, G. C., Ullah, H., Baxter, I., Callis, J., Sierra-Cajas, K., Elliott, K., Haswell, E. S., Zavala, M. E., Wildermuth, M., Williams, M., Ayalew, M., Henkhaus, N., Prunet, N., Lemaux, P. G., . . . Dinneny, J. R. (2021). Broadening the impact of plant science through innovative, integrative, and inclusive outreach. *Plant Direct*, *5*(4). https://doi.org/10.1002/pld3.316
Frink, D. D., & Ferris, G. R. (1998). Accountability, impression management, and goal setting in the performance evaluation process. *Human relations*, *51*(10), 1259-1283.
Fulton, L. A. (2012). Science Notebooks: Teachers' Developing Beliefs, Practices, and Student Outcomes [Article]. *Action in Teacher Education*, *34*(2), 121-132. https://doi.org/10.1080/01626620.2012.677736
Funk, C., Rainie, L., & Page, D. (2015). *Public and scientists' views on science and society*. https://www.pewresearch.org/science/2015/01/29/public-and-scientists-views-on-science-and-society/
García, I. (2020). Asset-based community development (ABCD): Core principles. In *Research handbook on community development* (pp. 67-75). Edward Elgar Publishing.
Gauchat, G. (2011). The cultural authority of science: Public trust and acceptance of organized science. *Public Understanding of Science*, *20*(6), 751-770. https://doi.org/10.1177/0963662510365246
Gholam, A. P. (2019). Inquiry-based learning: Student teachers' challenges and perceptions. *Journal of Inquiry and Action in Education*, *10*(2), 6.
Gilbert, J. (2005). How Students Learn: Science in the Classroom. *Science Education - SCI EDUC*, *89*, 1043-1045. https://doi.org/10.1002/sce.20115

Gilfedder, M., Robinson, C. J., Watson, J. E. M., Campbell, T. G., Sullivan, B. L., & Possingham, H. P. (2019). Brokering Trust in Citizen Science. *Society & Natural Resources*, *32*(3), 292-302. https://doi.org/10.1080/08941920.2018.1518507

Gillies, R. M. (2023). Using Cooperative Learning to Enhance Students' Learning and Engagement during Inquiry-Based Science. *Education Sciences*, *13*(12), 1242.

Gladstone, J. R., & Cimpian, A. (2021). Which role models are effective for which students? A systematic review and four recommendations for maximizing the effectiveness of role models in STEM. *International Journal of STEM Education*, *8*(1). https://doi.org/10.1186/s40594-021-00315-x

Godfrey Lopez, F. (2024). Australian Secondary science teachers' perceptions about their classroom practices and student engagement – an analysis based on Science Capital Teaching Approach. *International Journal of Science Education*, *46*(11), 1117-1138. https://doi.org/10.1080/09500693.2023.2275327

Goff, E. E., Mulvey, K. L., Irvin, M. J., & Hartstone-Rose, A. (2020). The effects of prior informal science and math experiences on undergraduate STEM identity. *Research in Science & Technological Education*, *38*(3), 272-288.

Gomes, D., & McCauley, V. (2013). Science Outreach and Science Education: The Analysis of Dilemmasto Promote the Creation of the Third Space. *Život i škola, br.*, *29*((1/2013)), 372-384. https://www.researchgate.net/publication/324797473_Science_Outreach_and_Science_Education_The_Analysis_of_Dilemmasto_Promote_the_Creation_of_the_Third_Space/citations#full-text

González-Espada, W. J., Birriel, J., & Birriel, I. (2010). Discrepant events: A challenge to students' intuition. *The Physics Teacher*, *48*(8), 508-511.

Goodrum, D., Hackling, M. W., & Rennie, L. J. (2001). *The status and quality of teaching and learning of science in Australian schools*. Canberra, Australia

Goodrum, D., & Rennie, L. (2007). Australian school science education: National action plan 2008–2012, Volume 1, The national action plan. *Department of Education, Science and Training, Canberra. Retrieved January*, *16*, 2014.

Googins, B. K., & Rochlin, S. A. (2000). Creating the partnership society: Understanding the rhetoric and reality of cross-sectoral partnerships. *Business and society review*, *105*(1), 127-144.

Gormally, C., Brickman, P., Hallar, B., & Armstrong, N. (2009). Effects of inquiry-based learning on students' science literacy skills and confidence. *International journal for the scholarship of teaching and learning*, *3*(2), 16.

Goud, S., Sheats, J. L., & Mertz, A. F. (2023). Building Bridges, Earning Trust: The WHY and the HOW of Public Trust in Science.

Greany, T., Gu, Q., Handscomb, G., Varley, M., Manners, P., & Duncan, S. (2014). *School-university partnerships: fulfilling the potential. Summary Report: October 2014*. https://irep.ntu.ac.uk/id/eprint/27068/1/PubSub4447_Varley.pdf

Green, D., Billy, J., & Tapim, A. (2010). Indigenous Australians' knowledge of weather and climate. *Climatic change*, *100*(2), 337-354.

Habig, B., & Gupta, P. (2021). Authentic STEM research, practices of science, and interest development in an informal science education program. *International Journal of STEM Education*, *8*, 1-18.

Hansson, S. O. (2016). Experiments: Why and How? *Science and Engineering Ethics*, *22*(3), 613-632. https://doi.org/10.1007/s11948-015-9635-3

Harackiewicz, J. M., Rozek, C. S., Hulleman, C. S., & Hyde, J. S. (2012). Helping Parents to Motivate Adolescents in Mathematics and Science:An Experimental Test of a Utility-Value Intervention. *Psychological Science*, *23*(8), 899-906. https://doi.org/10.1177/0956797611435530

Harlen, W. (2013). Inquiry-based learning in science and mathematics. *Review of Science, Mathematics and ICT Education*, *7*, 9-33.

Harnik, P. G., & Ross, R. M. (2004). Models of inquiry-based science outreach to urban schools [Article]. *Journal of Geoscience Education*, *52*(5), 420-428. https://doi.org/10.5408/1089-9995-52.5.420
Harrison, N., & Skrebneva, I. (2020). Country as pedagogical: enacting an Australian foundation for culturally responsive pedagogy. *Journal of Curriculum Studies*, *52*(1), 15-26. https://doi.org/10.1080/00220272.2019.1641843
Hart, A., & Northmore, S. (2011). Auditing and evaluating university–community engagement: Lessons from a UK case study. *Higher Education Quarterly*, *65*(1), 34-58.
Haysom, J., & Bowen, G. M. (2010). *Predict, Observe, Explain: Activities enhancing scientific understanding*. NSTA Publisher.
Hellgren, J. M., & Lindberg, S. (2017). Motivating students with authentic science experiences: changes in motivation for school science. *Research in Science & Technological Education*, *35*(4), 409-426.
Henrich, J., Heine, S. J., & Norenzayan, A. (2010). The weirdest people in the world? *Behavioral and brain sciences*, *33*(2-3), 61-83.
Henriksen, E. K., Jensen, F., & Sjaastad, J. (2015). The role of out-of-school experiences and targeted recruitment efforts in Norwegian science and technology students' educational choice. *International Journal of Science Education, Part B*, *5*(3), 203-222.
Hill, N. E., & Tyson, D. F. (2009). Parental involvement in middle school: a meta-analytic assessment of the strategies that promote achievement. *Developmental psychology*, *45*(3), 740.
Hilton, M. L., Schweingruber, H. A., Education, D., & Council, N. (2005). *America's lab report: Investigations in High School Science*. https://doi.org/10.17226/11311
Holderman, E. C. (2015). *What Nonprofits Can Learn: Successes and Challenges of Nonprofit-Government Collaborations in the San Francisco Bay Area*. https://bpb-us-w2.wpmucdn.com/usfblogs.usfca.edu/dist/9/244/files/2016/05/Report-Holderman-2ig49bc.pdf
Holland, B. A. (2019). Factors and strategies that influence faculty involvement in public service. In *Building the Field of Higher Education Engagement* (pp. 55-62). Routledge.
Holstermann, N., Grube, D., & Bögeholz, S. (2010). Hands-on activities and their influence on students' interest. *Research in Science Education*, *40*, 743-757.
Husher, K. (2010). *Building an evaluation framework for Australian science and maths outreach programs in schools* University of Newcastle]. https://hdl.handle.net/1959.13/1311016
Hussar, K., Schwartz, S., Boiselle, E., & Noam, G. G. (2008). *Toward a Systematic Evidence-Base for Science in Out-of-School Time - The Role of Assessment*. N. Foundation. https://6dd8523b-d8cf-496e-b8bc-14acf6819929.filesusr.com/ugd/e45463_e0b0a07b7d814a1481c7700dcead11c9.pdf
Hyde, J. S., Canning, E. A., Rozek, C. S., Clarke, E., Hulleman, C. S., & Harackiewicz, J. M. (2017). The Role of Mothers' Communication in Promoting Motivation for Math and Science Course-Taking in High School. *Journal of Research on Adolescence*, *27*(1), 49-64. https://doi.org/10.1111/jora.12253
Hyde, J. S., Else-Quest, N. M., Alibali, M. W., Knuth, E., & Romberg, T. (2006). Mathematics in the home: Homework practices and mother–child interactions doing mathematics. *The Journal of Mathematical Behavior*, *25*(2), 136-152.
Ing, M. (2014). Can parents influence children's mathematics achievement and persistence in STEM careers? *Journal of Career Development*, *41*(2), 87-103.
Intemann, K. (2023). Science communication and public trust in science. *Interdisciplinary Science Reviews*, *48*(2), 350-365.
Irwin, A. (2015). Citizen science and scientific citizenship: Same words, different meanings. *Science communication today*, *2015*, 29-38.
Jackson, M. C., Galvez, G., Landa, I., Buonora, P., & Thoman, D. B. (2016). Science That Matters: The Importance of a Cultural Connection in Underrepresented Students' Science Pursuit. *CBE—Life Sciences Education*, *15*(3), ar42. https://doi.org/10.1187/cbe.16-01-0067

Jacobs, S. R., Bender, S., & McAdam, A. (2015). The dandelion evolution outreach program: Learning through inquiry-based community engagement [Article]. *Evolution: Education and Outreach*, *8*(1), Article 4. https://doi.org/10.1186/s12052-015-0033-8

Jannah, M., Supardi, Z., & Prabowo. (2020). Guided Inquiry Model with the REACT Strategy Learning Materials to Improve the Students' Learning Achievement. *IJORER : International Journal of Recent Educational Research*, *1*, 156-168. https://doi.org/10.46245/ijorer.v1i2.45

Jenkins, E. W., & Nelson, N. (2005). Important but not for me: Students' attitudes towards secondary school science in England. *Research in Science & Technological Education*, *23*(1), 41-57.

Jensen, E., & Buckley, N. (2014). Why people attend science festivals: Interests, motivations and self-reported benefits of public engagement with research. *Public Understanding of Science*, *23*(5), 557-573. https://doi.org/10.1177/0963662512458624

John D. Bransford, e., Committee on Developments in the Science of, L., Committee on Learning, R., Educational Practice, C. o. B., Social, S., & Education, N. R. C. (2000). *How people learn : brain, mind, experience, and school*. Expanded edition. Washington, D.C. : National Academy Press, [2000] ©2000. https://search.library.wisc.edu/catalog/9910030628202121

Jones, M. G., Chesnutt, K., Ennes, M., Macher, D., & Paechter, M. (2022). Measuring science capital, science attitudes, and science experiences in elementary and middle school students. *Studies in Educational Evaluation*, *74*, 101180. https://doi.org/https://doi.org/10.1016/j.stueduc.2022.101180

Joswick, C., & Hulings, M. (2023). A Systematic Review of BSCS 5E Instructional Model Evidence. *International Journal of Science and Mathematics Education*. https://doi.org/10.1007/s10763-023-10357-y

Kang, J. (2022). Interrelationship between inquiry-based learning and instructional quality in predicting science literacy. *Research in Science Education*, *52*(1), 339-355.

Kania, J., & Kramer, M. (2011). *Collective impact* (Stanford Social Innovation Review, Issue. https://www.humboldt.edu/sites/default/files/senate/2024-10/chair20written20report201-23-2018.pdf

Kanter, R. M. (1994). Collaborative advantage. *Harvard business review*, *72*(4), 96-108.

Kawalkar, A., & Vijapurkar, J. (2013). Scaffolding Science Talk: The role of teachers' questions in the inquiry classroom. *International Journal of Science Education*, *35*, 2004-2027. https://doi.org/10.1080/09500693.2011.604684

Kearney, M., Treagust, D., Yeo, S., & Zadnik, M. (2001). Student and Teacher Perceptions of the Use of Multimedia Supported Predict–Observe–Explain Tasks to Probe Understanding. *Research in Science Education*, *31*, 589-615. https://doi.org/10.1023/A:1013106209449

Kellogg. (2004). Logic model development guide. https://www.naccho.org/uploads/downloadable-resources/Programs/Public-Health-Infrastructure/KelloggLogicModelGuide_161122_162808.pdf

Kelly, S. B., & Bell, P. (2012). *Connecting science instruction to neighborhood life through collaborative design with community*. https://stemteachingtools.org/assets/landscapes/STEM-Teaching-Tool-73-Collaborative-Design-of-Science-Instruction.pdf

Ker, L. A., DeWitt, J., Osborne, J. F., Dillon, J. S., Wong, B., & Willis, B. (2013). ASPIRES Report: Young people's science and career aspirations, age 10–14. https://kclpure.kcl.ac.uk/ws/portalfiles/portal/64130521/ASPIRES_Report_2013.pdf

Kim, M., & Dopico, E. (2016). Science education through informal education. *Cultural studies of science education*, *11*, 439-445.

Knippenberg, M. T., Leak, A., Disseler, S., & Segarra, V. A. (2020). Establishing partnerships for science outreach inside and outside the undergraduate classroom. *Journal of Microbiology & Biology Education*, *21*(2), 20.

Koch, M., & Penuel, W. R. (2010). *Planning for scaling and sustaining afterschool STEM programs* Invited paper presented at the NSF ITEST Convening, St. Paul, MN,

https://www.researchgate.net/profile/William-Penuel/publication/228892556_Planning_for_Scaling_and_Sustaining_Afterschool_STEM_Programs/links/53ee15b80cf2981ada174858/Planning-for-Scaling-and-Sustaining-Afterschool-STEM-Programs.pdf
Kolb, D. (1984). *Experiential Learning: Experience As The Source Of Learning And Development* (Vol. 1). Pearson FT Press.
Kong, X., Dabney, K. P., & Tai, R. H. (2014). The association between science summer camps and career interest in science and engineering. *International Journal of Science Education, Part B*, *4*(1), 54-65.
Kontkanen, S., Koskela, T., Kanerva, O., Kärkkäinen, S., Waltzer, K., Mikkilä-Erdmann, M., & Havu-Nuutinen, S. (2024). Science capital as a lens for studying science aspirations – a systematic review. *Studies in Science Education*, 1-27. https://doi.org/10.1080/03057267.2024.2388931
Korkman, N., & Metin, M. (2021). The Effect of Inquiry-Based Collaborative Learning and Inquiry-Based Online Collaborative Learning on Success and Permanent Learning of Students. *Journal of Science Learning*, *4*(2), 151-159.
Krapp, A., & Prenzel, M. (2011). Research on interest in science: Theories, methods, and findings. *International Journal of Science Education*, *33*(1), 27-50.
Kretzmann, J., & McKnight, J. P. (1996). Assets-based community development. *Nat'l Civic Rev.*, *85*, 23.
Kretzmann, J. P., & McKnight, J. (1993). *Building communities from the inside out*. ACTA Publications.
Lambin, E. F., Kim, H., Leape, J., & Lee, K. (2020). Scaling up Solutions for a Sustainability Transition. *One Earth*, *3*(1), 89-96. https://doi.org/10.1016/j.oneear.2020.06.010
Latham, G. P. (2004). The motivational benefits of goal-setting. *Academy of Management Perspectives*, *18*(4), 126-129.
Laugksch, R. C. (2000). Scientific Literacy: A Conceptual Overview. *Science education*, *84*(1), 71-94. https://doi.org/10.1002/(SICI)1098-237X(200001)84:1<71::AID-SCE6>3.0.CO;2-C
Lemon, A., Bordenstein, S. R., & Bordenstein, S. R. (2020). Discover the microbes within! the Wolbachia project: citizen science and student-based discoveries for 15 years and counting. *Genetics*, *216*(2), 263-268.
Lewenstein, B. V., & Baram-Tsabari, A. (2022). How should we organize science communication trainings to achieve competencies? *International Journal of Science Education, Part B*, *12*(4), 289-308.
Li, Q. (1999). Teachers' beliefs and gender differences in mathematics: A review. *Educational Research*, *41*(1), 63-76.
Lin, T.-C., Hsu, Y.-S., Lin, S.-S., Changlai, M.-L., Yang, K.-Y., & Lai, T.-L. (2011). A review of empirical evidence on scaffolding for science education. *International Journal of Science and Mathematics Education*, *10*. https://doi.org/10.1007/s10763-011-9322-z
Llewellyn, D. (2012). *Teaching high school science through inquiry and argumentation*. Corwin Press.
Lloyd, A., Gore, J., Holmes, K., Smith, M., & Fray, L. (2018). Parental influences on those seeking a career in STEM: The primacy of gender. *International Journal of Gender, Science and Technology*, *10*(2), 308-328.
Locke, E. A., & Latham, G. P. (2002). Building a practically useful theory of goal setting and task motivation: A 35-year odyssey. *American psychologist*, *57*(9), 705.
Locke, E. A., & Latham, G. P. (2019). The development of goal setting theory: A half century retrospective. *Motivation Science*, *5*(2), 93.
Lucas, A. M. (1983). Scientific literacy and informal learning. *Studies in Science Education*, *10*(1), 1-36.
Luehmann, A. L. (2009). Students' perspectives of a science enrichment programme: Out-of-school inquiry as access [Article]. *International Journal of Science Education*, *31*(13), 1831-1855. https://doi.org/10.1080/09500690802354195
M. Suzanne Donovan, J. D. B., James W. Pellegrino, e., Committee on Learning, R., Educational Practice, C. o. B., Social, S., & Education, N. R. C. (1999). *How people learn : bridging research and practice*.

Washington, DC : National Academy Press : U.S. Dept. of Education, Office of Educational Research and Improvement, Educational Resources Information Center, [1999]. https://search.library.wisc.edu/catalog/999914697802121
Maarschalk, J. (1988). Scientific literacy and informal science teaching. *Journal of Research in Science Teaching*, *25*(2), 135-146.
Manz, E. (2015). Representing student argumentation as functionally emergent from scientific activity. *Review of Educational Research*, *85*(4), 553-590.
Markowitz, D. G. (2004). Evaluation of the long-term impact of a university high school summer science program on students' interest and perceived abilities in science. *Journal of Science Education and Technology*, *13*, 395-407.
Marotto, C. C. F., & Milner-Bolotin, M. (2018). Parental engagement in children's STEM education. Part II: Parental attitudes and motivation. *Lumat: International Journal of Math, Science and Technology Education*, *6*(1). https://doi.org/10.31129/lumat.6.1.293
Marshall, J. C., & Horton, R. M. (2011). The relationship of teacher-facilitated, inquiry-based instruction to student higher-order thinking. *School Science and Mathematics*, *111*(3), 93-101.
Martins Gomes, D., & McCauley, V. (2016). Dialectical dividends: fostering hybridity of new pedagogical practices and partnerships in science education and outreach [Article]. *International Journal of Science Education*, *38*(14), 2259-2283. https://doi.org/10.1080/09500693.2016.1234729
Martins Gomes, D., & McCauley, V. (2021). Creativity in science: A dilemma for informal and formal education [Article]. *Science education*, *105*(3), 498-520. https://doi.org/10.1002/sce.21614
Mathews, D. J., Kalfoglou, A., & Hudson, K. (2005). Geneticists' views on science policy formation and public outreach. *American Journal of Medical Genetics Part A*, *137*(2), 161-169.
Mau, W. C. J., & Li, J. (2018). Factors Influencing STEM Career Aspirations of Underrepresented High School Students. *The Career Development Quarterly*, *66*(3), 246-258. https://doi.org/10.1002/cdq.12146
McCauley, V., & Davison, K. (2024). The Power of Science Outreach-Conscious Teachers. Conference Proceedings. New Perspectives in Science Education 2024,
McCauley, V., Martins Gomes, D., & Davison, K. G. (2018). Constructivism in the third space: challenging pedagogical perceptions of science outreach and science education [Article]. *International Journal of Science Education, Part B: Communication and Public Engagement*, *8*(2), 115-134. https://doi.org/10.1080/21548455.2017.1409444
McCreedy, D., & Dierking, L. D. (2013). *CASCADING INFLUENCES: Long-Term Impacts of Informal STEM Experiences for Girls* https://njstempathways.org/wp-content/uploads/2017/08/cascading-influences-long-term-influence-of-informal-stem-for-girls-mccreedy.pdf
McDavid, J. C., Huse, I., & Hawthorn, L. R. (2018). *Program evaluation and performance measurement: An introduction to practice*. Sage Publications.
McHugh, M., & McCauley, V. (2017). Hooked on Science. *Science in School*(39), 55-59. https://www.scienceinschool.org/wp-content/uploads/2017/03/issue39_hooks.pdf
McKinley, E., Garcia Rojas, M., Palacios, M., Nichols, C., Bhattacharjee, A., & Macreadie, P. (2024). Immersive citizen science experiences and their role in changing perceptions of coastal wetlands. *People and Nature*, *6*(6), 2261-2282.
McLean, K. G. (2010). *Advance Guard: climate change impacts, adaptation,*

mitigation and indigenous peoples - A compendium of case studies.
Melhuish, E. C. (2011). Preschool matters. *Science*, *333*(6040), 299-300.
Melhuish, E. C., Sylva, K., Sammons, P., Siraj-Blatchford, I., Taggart, B., Phan, M. B., & Malin, A. (2008). Preschool influences on mathematics achievement. *Science*, *321*(5893), 1161-1162.
Merton, R. K. (1968). The Matthew effect in science: The reward and communication systems of science are considered. *Science*, *159*(3810), 56-63.
Miller, B., & Martin, C. (2016). Digital notebooks for digital natives. *Science and Children*, *53*(5), 84.

Miller, J. D. (1998). The measurement of civic scientific literacy. *Journal of Public Understanding of Science*, *7*(3), 203-223.
Milner-Bolotin, M., & Marotto, C. C. (2018). Parental engagement in children's STEM education. Part I: Meta-analysis of the literature. *LUMAT: International Journal on Math, Science and Technology Education*, *6*(1), 41–59-41–59.
Mirabueno, D. (2023). *The Taxonomy of Predict-Observe-Explain (POE) as a Teaching Strategy and Thinking Process of Chemistry Stakeholders*. https://doi.org/10.21203/rs.3.rs-3401672/v1
Muijs, D., & Bokhove, C. (2020). *Metacognition and Self-Regulation: Evidence Review*. https://educationendowmentfoundation.org.uk/evidence-summaries/evidence-reviews/metacognition-and-self-regulation-review/
Mutlu, A. (2023). React Strategy Instruction Enriched with Inquiry-Based Experiments: Exploring Middle School Students' Understanding of Mixtures. *Journal of Science Learning*, *6*(4), 401-413.
Myers, T. A., Maibach, E. W., Roser-Renouf, C., & Akerlof, K. (2012). The relationship between personal experience and belief in the reality of global warming. *Nature Climate Change*, *3*, 343-347. https://doi.org/10.1038/nclimate1754
NASM, & National Academies of Sciences, E. a. M. (2016). Evaluation to Refine Goals and Demonstrate Effectiveness. In *Effective Chemistry Communication in Informal Environments*. National Academies Press (US). https://www.ncbi.nlm.nih.gov/books/NBK385012/
Neher-Asylbekov, S., & Wagner, I. (2023). Modelling of interest in out-of-school science learning environments: a systematic literature review. *International Journal of Science Education*, *45*(13), 1074-1096. https://doi.org/10.1080/09500693.2023.2185830
Nisbet, M. C. (2008). Framing Science: A New Paradigm in Public Engagement. In L. Kahlor & P. Stout (Eds.), *Commnicating Science*. Routledge.
OECD. (2006). *Assessing scientific, reading and mathematical literacy - A frame work for PISA 2006*. https://www.oecd.org/en/publications/assessing-scientific-reading-and-mathematical-literacy_9789264026407-en.html#:~:text=Abstract-,Assessing%20Scientific%2C%20Reading%20and%20Mathematical%20Literacy:%20A%20Framework%20for%20PISA,also%20illustrated%20with%20sample%20tasks.
OECD. (2008). *Encouraging Student Interest in Science and Technology Studies, OECD Publishing, Paris*. https://www.oecd.org/en/publications/encouraging-student-interest-in-science-and-technology-studies_9789264040892-en.html
OECD. (2024). *Shared challenges, transformative actions: OECD Science and Technology Policy Ministerial*. https://cdn-assets.inwink.com/693d4b04-1de5-4c06-808d-2f0c6b423782/b2ab8631-88dd-465d-b1aa-ed4067f7faef?sv=2018-03-28&sr=b&sig=sYSOgCCA8eU3UgGspu4hQCTDKUfy03VllNnjh2F%2FGFw%3D&se=9999-12-31T23%3A59%3A59Z&sp=r&rscd=inline%3B%20filename%3D%22MIN24-KEY%2520Issues%2520Note%2520BRA.pdf%22
OECD. (2025). *PISA 2025 SCIENCE FRAMEWORK (DRAFT)*. https://pisa-framework.oecd.org/science-2025/assets/docs/PISA_2025_Science_Framework.pdf
Osborne, J., Simon, S., & Collins, S. (2003). Attitudes towards science: A review of the literature and its implications. *International Journal of Science Education*, *25*(9), 1049-1079.
Owen, J. M. (2020). *Program evaluation: Forms and approaches*. Routledge.
Paek, S., & Fulton, L. (2021). Digital Science Notebooks: A Tool for Supporting Scientific Literacy at the Elementary Level [Article]. *TechTrends*, *65*(3), 359-370. https://doi.org/10.1007/s11528-020-00579-0
Palmer, D. (2004). Situational interest and the attitudes towards science of primary teacher education students. *International Journal of Science Education*, *26*(7), 895-908.

Palmer, D., Dixon, J., & Archer, J. (2017). Using situational interest to enhance individual interest and science-related behaviours. *Research in Science Education*, *47*, 731-753.
Pandya, R. E. (2012). A framework for engaging diverse communities in citizen science in the US. *Frontiers in Ecology and the Environment*, *10*(6), 314-317.
Patton, M. Q. (2008). Future trends in evaluation. *From policies to results: Developing capacities for country monitoring and evaluation systems. Paris: UNICEF and IPEN*, 44-56.
Pedaste, M., Mäeots, M., Siiman, L. A., de Jong, T., van Riesen, S. A. N., Kamp, E. T., Manoli, C. C., Zacharia, Z. C., & Tsourlidaki, E. (2015). Phases of inquiry-based learning: Definitions and the inquiry cycle. *Educational Research Review*, *14*, 47-61. https://doi.org/https://doi.org/10.1016/j.edurev.2015.02.003
Perry, J., Lundie, D., & Golder, G. (2019). Metacognition in schools: what does the literature suggest about the effectiveness of teaching metacognition in schools? *Educational Review*, *71*(4), 483-500. https://doi.org/10.1080/00131911.2018.1441127
Philip, T. M., & Azevedo, F. S. (2017). Everyday science learning and equity: Mapping the contested terrain. *Science education*, *101*(4), 526-532.
Phillips, T., Porticella, N., Constas, M., & Bonney, R. (2018). A framework for articulating and measuring individual learning outcomes from participation in citizen science. *Citizen science: Theory and practice*, *3*(2).
Piaget, J. (1952). *The origins of intelligence in children* [doi:10.1037/11494-000]. W W Norton & Co. https://doi.org/10.1037/11494-000
Plummer, J. D., Zahm, V. M., & Rice, R. (2010). Inquiry and astronomy: Preservice teachers' investigations of celestial motion [Article]. *Journal of Science Teacher Education*, *21*(4), 471-493. https://doi.org/10.1007/s10972-010-9189-9
Polanin, J. R., Austin, M., Taylor, J. A., Steingut, R. R., Rodgers, M. A., & Williams, R. (2024). Effects of the 5E Instructional Model: A Systematic Review and Meta-Analysis. *AERA Open*, *10*, 23328584241269866. https://doi.org/10.1177/23328584241269866
Poliakoff, E., & Webb, T. L. (2007). What Factors Predict Scientists' Intentions to Participate in Public Engagement of Science Activities? *Science Communication*, *29*(2), 242-263. https://doi.org/10.1177/1075547007308009
Prain, V., & Tytler, R. (2012). Learning through constructing representations in science: A framework of representational construction affordances. *International Journal of Science Education*, *34*(17), 2751-2773.
PrimaryConnections. (2024). *Our evidence-informed approach: Launch > Inquire > Act*. https://primaryconnections.org.au/about-program/our-evidence-informed-approach
Prober, S. M., O'Connor, M. H., & Walsh, F. J. (2011). Australian Aboriginal peoples' seasonal knowledge: a potential basis for shared understanding in environmental management. *Ecology and society*, *16*(2).
PWC. (2015). *A smart move: Future proofing Australia's workforce by growing skills in STEM*. https://www.pwc.com.au/pdf/a-smart-move-pwc-stem-report-april-2015.pdf
Qld-State-Govt. (2024). *Future Queensland Science Strategy 2024-2029*. Q. S. Govt. https://science.desi.qld.gov.au/__data/assets/pdf_file/0016/352051/future-qld-science-strategy.pdf
Ramirez, A. G. (2011). Science Saturdays: A simple science outreach model to achieve broad impact. *MRS Online Proceedings Library (OPL)*, *1320*, mrsf10-1320-xx1301-1303.
Raque-Bogdan, T. L., Klingaman, E. A., Martin, H. M., & Lucas, M. S. (2013). Career-related parent support and career barriers: An investigation of contextual variables. *The Career Development Quarterly*, *61*(4), 339-353.

Redman, C. M., Tomiya, S., Bitterman, K., Cain, K., & Meachen, J. A. (2021). Utilizing inquiry-driven science outreach to curate Natural Trap Cave fossils and inspire the pursuit of STEM careers [Article]. *Evolution: Education and Outreach*, *14*(1), Article 13. https://doi.org/10.1186/s12052-021-00152-0

Reed, M. S., Duncan, S., Manners, P., Pound, D., Armitage, L., Frewer, L., Thorley, C., & Frost, B. (2018). A common standard for the evaluation of public engagement with research. *Research for All*, *2*(1).

Reed, S., Prieto, E., Burns, T., & O'Connor, J. (2021). STEM Outreach: Are We Making a Difference? A Case Study Evaluating the Science and Engineering Challenge Program. *Journal of Higher Education Outreach and Engagement*, *25*(2), 59-77.

Rennie, L. (2006). *The community's contribution to science learning: Making it count* https://research.acer.edu.au/research_conference_2006/8/

Rennie, L. J., Goodrum, D., & Hackling, M. (2001). Science teaching and learning in Australian schools: Results of a national study. *Research in Science Education*, *31*, 455-498.

Rennie, L. J., Goodrum, D., & Hackling, M. (2001). The state of science in Australian secondary schools. *Australian Science Teachers Journal*, *47*(4).

Renninger, K. A. (2007). *Interest and motivation in informal science learning* (Commissioned Paper for Learning Science in Informal Environments Committee, Issue. https://sites.nationalacademies.org/cs/groups/dbassesite/documents/webpage/dbasse_080085.pdf

Riegle-Crumb, C., Moore, C., & Ramos-Wada, A. (2011). Who wants to have a career in science or math? Exploring adolescents' future aspirations by gender and race/ethnicity. *Science education*, *95*(3), 458-476.

Risien, J., & Storksdieck, M. (2018). Unveiling Impact Identities: A Path for Connecting Science and Society. *Integrative Comparative Biology &*, *58*(1), 58-66.

Rose, D. C., Amano, T., González-Varo, J. P., Mukherjee, N., Robertson, R. J., Simmons, B. I., Wauchope, H. S., & Sutherland, W. J. (2019). Calling for a new agenda for conservation science to create evidence-informed policy. *Biological Conservation*, *238*, 108222.

Ruiz-Primo, M. A., Li, M., Ayala, C., & Shavelson, R. J. (2004). Evaluating students' science notebooks as an assessment tool. *International Journal of Science Education*, *26*(12), 1477-1506.

Sadler, K., Eilam, E., Bigger, S., & Barry, F. (2018). University-led STEM outreach programs: purposes, impacts, stakeholder needs and institutional support at nine Australian universities. *Studies in Higher Education*, *43*, 586-599. https://doi.org/10.1080/03075079.2016.1185775

Sadler, K., Eilam, E., Bigger, S. W., & Barry, F. (2018). University-led STEM outreach programs: purposes, impacts, stakeholder needs and institutional support at nine Australian universities. *Studies in Higher Education*, *43*(3), 586-599. https://doi.org/10.1080/03075079.2016.1185775

Sam, R. (2024). Systematic review of inquiry-based learning: assessing impact and best practices in education. *F1000Research*, *13*, 1045.

Samsudin, A., Rusdiana, D., Efendi, R., Janeusse Fratiwi, N., Hadiana Aminudin, A., & Adimayuda, R. (2021). Development of Predict-Observe-Explain (POE) Strategy Assisted by Rebuttal Texts on Newton's Law Material with Rasch Analysis. *Tadris Jurnal Keguruan dan Ilmu Tarbiyah*, 103-115. https://doi.org/10.24042/tadris.v6i1.7641

San Miguel, S. F., McDavid, L., Parker, L. C., & Simons, M. C. (2019). Developing a scalable STEM career development program for elementary school-aged students. *Journal of STEM outreach*, *2*, 10.15695/jstem/v15692i15691. 15621.

Sarkar, S., & Frazier, R. (2008). Place-based investigations and authentic inquiry. *The science teacher*, *75*(2), 29.

Satterthwait, D. (2010). Why are'hands-on'science activities so effective for student learning? *Teaching Science*, *56*(2), 7.

Scheufele, D. A. (2014). Science communication as political communication. *Proceedings of the National Academy of Sciences*, *111*(supplement_4), 13585-13592. https://doi.org/doi:10.1073/pnas.1317516111
Scheufele, D. A., & Krause, N. M. (2019). Science audiences, misinformation, and fake news. *Proceedings of the National Academy of Sciences*, *116*(16), 7662-7669. https://pmc.ncbi.nlm.nih.gov/articles/PMC6475373/pdf/pnas.201805871.pdf
Schraw, G., Crippen, K. J., & Hartley, K. (2006). Promoting self-regulation in science education: Metacognition as part of a broader perspective on learning. *Research in Science Education*, *36*(1-2), 111-139. https://doi.org/10.1007/s11165-005-3917-8
Schuster, C., & Martiny, S. E. (2017). Not feeling good in STEM: Effects of stereotype activation and anticipated affect on women's career aspirations. *Sex Roles*, *76*(1), 40-55.
Scott, D. L., Sharma, R., Godwyll, F., Johnson, J., & Putman, T. (2020). Building on strengths to address challenges: an asset-based approach to planning and implementing a community partnership school. *Journal of Higher Education Outreach and Engagement*, *24*(2), 69-84.
Selsky, J. W., & Parker, B. (2005). Cross-sector partnerships to address social issues: Challenges to theory and practice. *Journal of management*, *31*(6), 849-873.
Shanley, P., & López, C. (2009). Out of the loop: why research rarely reaches policy makers and the public and what can be done. *Biotropica*, *41*(5), 535-544.
Shechter, O. G., Durik, A. M., Miyamoto, Y., & Harackiewicz, J. M. (2011). The role of utility value in achievement behavior: The importance of culture. *Personality and social psychology bulletin*, *37*(3), 303-317.
Sheldon, K. M., & Elliot, A. J. (1999). Goal striving, need satisfaction, and longitudinal well-being: the self-concordance model. *Journal of personality and social psychology*, *76*(3), 482.
Simon, B. S. (2004). High School Outreach and Family Involvement. *Social Psychology of Education*, *7*(2), 185-209. https://doi.org/10.1023/b:spoe.0000018559.47658.67
Skarlatidou, A., Haklay, M., Hoyte, S., van Oudheusden, M., & Bishop, I. J. (2024). How can bottom-up citizen science restore public trust in environmental governance and sciences? Recommendations from three case studies. *Environmental Science & Policy*, *160*, 103854. https://doi.org/https://doi.org/10.1016/j.envsci.2024.103854
Slotkin, R., Bierman, K. L., Heinrichs, B. S., & Welsh, J. A. (2024). Parent Outreach Efforts Extend the Sustained Benefits of a Preschool Classroom Intervention: Adolescent Follow-Up of a Randomized Controlled Trial. *Prevention Science*, *25*(8), 1217-1227. https://doi.org/10.1007/s11121-024-01758-8
Stahl, G., Laura, S., Sarah, M., & and Lunn, J. (2021). Middle years students' engagement with science in rural and urban communities in Australia: exploring science capital, place-based knowledges and familial relationships. *Pedagogy, Culture & Society*, *29*(1), 43-60. https://doi.org/10.1080/14681366.2019.1684351
Stilgoe, J., Lock, S. J., & Wilsdon, J. (2014). Why should we promote public engagement with science? *Public Understanding of Science*, *23*(1), 4-15. https://doi.org/10.1177/0963662513518154
Stockdale, R., & Keane, T. (2016). Influencing the influencers: The role of mothers in IT career choices. *Journal of Information Technology Education: Innovations in Practice*, *15*, 181-194. https://doi.org/10.28945/3624
Stocklmayer, S., Rennie, L., & Gilbert, J. (2010). The roles of the formal and informal sectors in the provision of effective science education. *Studies in Science Education*, *46*, 1-44. https://doi.org/10.1080/03057260903562284
Stone, B. (2020). Understanding the Influence of Teacher-Directed Scientific Inquiry on Students' Primal Inquiries in Two American Science Classrooms [Article]. *Journal of Research in Childhood Education*, *34*(4), 521-537. https://doi.org/10.1080/02568543.2020.1718807

Storksdieck, M., Stylinski, C., & Bailey, D. (2016). *Typology for Public Engagement with Science: A Conceptual Framework for Public Engagement Involving Scientists*. http://www.aaas.org/sites/default/files/content_files/AAAS_Typology.pdf

Susiloningsih, E., Sumantri, M. S., & Marini, A. (2023). Experiential Learning Model in Science Learning: Systematic Literature Review. *Jurnal Penelitian Pendidikan IPA*, *9*(9), 550-557. https://doi.org/10.29303/jppipa.v9i9.4452

Taffere, G. R., Abebe, H. T., Zerihun, Z., Mallen, C., Price, H. P., & Mulugeta, A. (2024). Systematic review of community engagement approach in research: describing partnership approaches, challenges and benefits. *Journal of Public Health*, *32*(2), 185-205. https://doi.org/10.1007/s10389-022-01799-9

Tang, X., & Zhang, D. (2020). How informal science learning experience influences students' science performance: A cross-cultural study based on PISA 2015. *International Journal of Science Education*, *42*(4), 598-616.

Tran, J., Lyon, K., McLeod, K., Jamison, A., Farrokh, S., Wolf, J., Swani, A., Cheung, K., Usprech, J., & D'Entremont, A. (2024). Economic, cultural, and science capital: Familial factors shaping access to STEM outreach programs for children and youth. *Proceedings of the Canadian Engineering Education Association (CEEA)*. https://doi.org/10.24908/pceea.2024.18561

Treagust, D. (2008). The Role of Multiple Representations in Learning Science: Enhancing Students' Conceptual Understanding and Motivation. In Y.-J. Lee & A.-L. Tan (Eds.), *Science Education at the Nexus of Theory and Practice* (pp. 7-23). Sense Publishers. https://doi.org/10.1163/9789087904227_003

Treagust, D. F., Mthembu, Z., & Chandrasegaran, A. L. (2014). Evaluation of the Predict-Observe-Explain Instructional Strategy to Enhance Students' Understanding of Redox Reactions. In I. Devetak & S. A. Glažar (Eds.), *Learning with Understanding in the Chemistry Classroom* (pp. 265-286). Springer Netherlands. https://doi.org/10.1007/978-94-007-4366-3_14

Tulloch, A. I., Possingham, H. P., Joseph, L. N., Szabo, J., & Martin, T. G. (2013). Realising the full potential of citizen science monitoring programs. *Biological Conservation*, *165*, 128-138.

Tural, G., Akdeniz, A. R., & Alev, N. (2010). Effect of 5E teaching model on student teachers' understanding of weightlessness. *Journal of Science Education and Technology*, *19*, 470-488.

Tytler, R. (2007). Re-imagining science education: Engaging students in science for Australia's future. *Teaching Science*, *53*(4), 14-17.

Tytler, R., & Hubber, P. (2016). Constructing representations to learn science. In *Using multimodal representations to support learning in the science classroom* (pp. 159-181). Springer.

Valle, N., Antonenko, P., Endara, L., Davis, E. C., Somarriba, G., Sessa, E., Luo, F., Carey, S., Dogan, S., Burleigh, J. G., & McDaniel, S. (2021). Community Science, Storytelling, or Inquiry-Based Learning? Evaluating Three Technology-Enhanced Pedagogical Approaches in an Online Botany Course [Article]. *American Biology Teacher*, *83*(8), 513-520. https://doi.org/10.1525/abt.2021.83.8.513

van Aalderen-Smeets, S. I., Walma van der Molen, J. H., & Asma, L. J. (2012). Primary teachers' attitudes toward science: A new theoretical framework. *Science education*, *96*(1), 158-182.

Van Lunenburg, M., Geuijen, K., & Meijer, A. (2020). How and Why Do Social and Sustainable Initiatives Scale? A Systematic Review of the Literature on Social Entrepreneurship and Grassroots Innovation. *VOLUNTAS: International Journal of Voluntary and Nonprofit Organizations*, *31*(5), 1013-1024. https://doi.org/10.1007/s11266-020-00208-7

Van Tuijl, C., & van der Molen, J. H. W. (2016). Study choice and career development in STEM fields: An overview and integration of the research. *International journal of technology and design education*, *26*(2), 159-183.

Van Tulder, R., Seitanidi, M. M., Crane, A., & Brammer, S. (2016). Enhancing the impact of cross-sector partnerships: Four impact loops for channeling partnership studies. *Journal of Business Ethics*, *135*, 1-17.

van Uum, M. S. J., Verhoeff, R. P., & Peeters, M. (2017). Inquiry-based science education: scaffolding pupils' self-directed learning in open inquiry. *International Journal of Science Education*, *39*(18), 2461-2481. https://doi.org/10.1080/09500693.2017.1388940

Vangen, S., & Huxham, C. (2005). Aiming for collaborative advantage: Challenging the concept of shared vision. *Advanced Institute of Management Research Paper No. 015*. https://doi.org/10.2139/ssrn.1306963

Vass, G. (2017). Preparing for culturally responsive schooling: Initial teacher educators into the fray. *Journal of teacher education*, *68*(5), 451-462.

Vaupotič, N., Kienhues, D., & Jucks, R. (2021). Trust in Science and Scientists: Implications for (Higher) Education. In (pp. 207-220). https://doi.org/10.1007/978-3-030-72945-5_10

Vygotsky, L. S. (1978). *Mind in society: the development of higher psychological processes*.

Weingart, P., Joubert, M., & Connoway, K. (2021). Public engagement with science—Origins, motives and impact in academic literature and science policy. *PLOS ONE*, *16*(7), e0254201. https://doi.org/10.1371/journal.pone.0254201

White, R., & Gunstone, R. (2014). Probing Understanding. https://doi.org/10.4324/9780203761342

Woitowich, N., Hunt, G., Muhammad, L., & Garbarino, J. (2021). Assessing Motivations and Barriers to Science Outreach within Academia: A Mixed-Methods Survey. *Frontiers in Communication*, *7*(907762). https://doi.org/10.3389/fcomm.2022.907762

Wood, A., & Wood, R. *Kids Teaching Kids Program*. https://www.ryde.nsw.gov.au/files/assets/public/v/1/environment/reen/kids-teaching-kids-program.pdf

Wood, D., Bruner, J. S., & Ross, G. (1976). The role of tutoring in problem solving. *Journal of child psychology and psychiatry*, *17*(2), 89-100.

Woods-McConney, A., Oliver, M., 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.

Woolnough, B. E. (1994). Factors affecting students' choice of science and engineering. *International Journal of Science Education*, *16*(6), 659-676.

Wynne, B. (2006). Public Engagement as a Means of Restoring Public Trust in Science – Hitting the Notes, but Missing the Music? *Community Genetics*, *9*(3), 211-220. https://doi.org/10.1159/000092659

Xia, X., Bentley, L. R., Fan, X., & Tai, R. H. (2024). STEM Outside of School: a Meta-Analysis of the Effects of Informal Science Education on Students' Interests and Attitudes for STEM. *International Journal of Science and Mathematics Education*, 1-29.

Xu, L., Gauthier, A. H., & Strohschein, L. (2009). Why are some children left out? Factors barring Canadian children from participating in extracurricular activities. *Canadian Studies in Population [ARCHIVES]*, *36*(3-4), 325-345.

YouthInsight. (2022(a)). *2022 STEM Influencer Report – Parents*. https://youthinsight.com.au/wp-content/uploads/2023/08/stem-influencer-report-parent-survey-2022-23.pdf

YouthInsight. (2022(b)). *2022 STEM Influencer Report – Teachers & Career Advisors*. https://youthinsight.com.au/wp-content/uploads/2023/07/stem-influencer-report-teacher-and-career-advisor-survey-2022-23.pdf

YouthInsight. (2023). *2023 Youth in STEM Report*. https://youthinsight.com.au/wp-content/uploads/2024/09/Youth-in-STEM_2023-Report-FINAL.pdf

Yuan, S., Oshita, T., AbiGhannam, N., Dudo, A., Besley, J. C., & Koh, H. E. (2017). Two-way communication between scientists and the public: a view from science communication trainers in North America. *International Journal of Science Education, Part B*, *7*(4), 341-355.

Yunkaporta, T. (2009). *Aboriginal pedagogies at the cultural interface* James Cook University]. https://researchonline.jcu.edu.au/10974/21/JCU_10974_Yunkaporta_2009_thesis.pdf

Yunkaporta, T. K. (2010). Our ways of learning in Aboriginal languages. In J. Hobson, K. Lowe, S. Poetsch, & M. Walsh (Eds.), *Re-Awakening Languages* (pp. 37-49). Sydney University Press.

Zack, R., Vacha, E. F., & Staub, N. L. (2017). Science in Action! Outreach Program Promotes Confidence in Teaching Science [Article]. *American Biology Teacher*, *79*(9), 711-719. https://doi.org/10.1525/abt.2017.79.9.711

Zamboni, K., Schellenberg, J., Hanson, C., Betran, A. P., & Dumont, A. (2019). Assessing scalability of an intervention: why, how and who? *Health policy and planning*, *34*(7), 544-552. https://pmc.ncbi.nlm.nih.gov/articles/PMC6788216/pdf/czz068.pdf

Zivtins, R. (2022). *Evaluating Science Outreach: Case Study in the Wohl Reach Out Lab* Imperial College London]. https://core.ac.uk/download/pdf/521093126.pdf

9.0 Appendices

The following is a list of the appendices referenced in this report, which are available as a separate document entitled *Best Practice Principles for Community Science Engagement Programs – Appendices*.

A. Resources for Overall Program Design

B. Evaluation Frameworks and Evaluation Tools

C. Capabilities and Capacity

D. Sustainability and Scalability

E. Strategic Alliances – Collaborations and Partnerships

F. Inclusivity and Accessibility Resources

G. Inquiry Based Learning (IBL) Resources

H. Hands-on Experiential Learning Resources

I. Resources for Engaging Scientists in Community Science Programs

J. Resources to Influence the Influencers

K. Informal Learning Places, Programs and Training Opportunities

L. Leveraging Local Assets

The Department of the Environment, Tourism, Science and Innovation acknowledges Aboriginal and Torres Strait Islander peoples as the Traditional Owners and custodians of the land.

We recognise their connection to land, sea and community, and pay our respects to Elders past and present.

Queensland Government