PASL

PRINCIPALS AS STEM LEADERS

BUILDING THE EVIDENCE BASE FOR IMPROVED STEM LEARNING

FINAL REPORT

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PASL PROJECT

The project was undertaken by a consortium led by the University of Tasmania in collaboration with the Australian Catholic University, The University of New South Wales, Flinders University, Macquarie University, University of Notre Dame Australia, University of Queensland, and University of Sydney, as well as the presidents of both the Australian Primary Principals Association and the Australian Secondary Principals Association. The team also included an external evaluation team, led by Dr Gail Dennett.

This publication reports on the 'Principals as STEM Leaders' (PASL) project. The views expressed herein are those of the authors and do not necessarily represent the views of the Australian Government. This publication also does not constitute any form of professional advice and should not be relied on as such.

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Foreword

The *Principals as STEM Leaders project: Building the Evidence Base for Improved STEM Learning* (PASL) commenced in 2018 and was completed by the end of 2020.

PASL was funded by the Australian Government Department of Education, Skills, and Employment (DESE), under the *Inspiring all Australians in Digital Literacy and STEM – Embracing the Digital Age* initiative of the National Innovation and Science Agenda (NISA). PASL resources are designed to support principals' leadership of whole-of-school approaches to STEM teaching and learning. PASL professional learning resources and case studies are available on the PASL website[1], hosted by the Australian Secondary Principals Association (ASPA).

The project was undertaken by a consortium led by the University of Tasmania, in collaboration with the Australian Catholic University and the support of Flinders University, Macquarie University, The University of Queensland, The University of Notre Dame Australia and The University of Sydney, as well as the presidents of both the Australian Primary and Secondary Principals Associations. A Project Reference Group (RG) and evaluation team were established to provide advice and support throughout the project.

This report summarises the theoretical underpinnings of the PASL project and the approach to creating and trialling resources. The report also presents research findings that contributed to the evaluation of both the quality and effectiveness of the project. We are confident that PASL professional learning resources and case studies of exemplary STEM education leadership will support STEM education stakeholders to imagine and achieve STEM education that is exciting, engaging, and effective in promoting positive student learning outcomes.

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July 2022

[1] See https://www.pasl.asn.au

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- Principals and school leadership teams of the participating schools for their enthusiasm and contribution.
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Glossary
of acronyms, abbreviations and terms

AC	Australian Curriculum
AITSL	Australian Institute for Teaching and School Leaders
ASMS	The Australian Science and Mathematics School
APPA	Australian Primary Principals Association
ASPA	Australian Secondary Principals Association
BPS	Brookman Primary School
CC	Cerdon College
Critical friend model	A model for supporting principals to develop collegial relationships, encouraging reflective practice, and rethinking leadership.
CS	Case Study
CSP	Case Study participants
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DESE	Department of Education, Skills, and Employment
DoE	Department of Education
HFPS	Hagley Farm Primary School
ICSEA	Index of Community Socio-Educational Advantage
Integrated STEM education	A combined, cross-disciplinary, approach to individual STEM knowledge, effective pedagogical practices, and, in the context of learning, AC capabilities into one learning experience.
K	Kindergarten
KLA	Key Learning Area
LCK	Leadership Content Knowledge (Nelson, 2010).
NISA	National Innovation and Science Agenda
PALL	Principals as Literacy Leaders programme
PASL	Principals as STEM leaders
PL	Professional Learning
QPLF	Quality Professional Learning Framework
RG	Reference Group
STEAM	STEM incorporating Arts – dance, drama, music, visual arts, design, and new media and sometimes humanities and language arts.
STEM	The acronym STEM is itself used in different ways. For the purposes of this project, STEM constitutes individual subjects/disciplines: science, technology, engineering, and mathematics, as well as integrated STEM.
STEM Capability Sets	The dimensions of STEM capability (*STEM discipline-specific and interdisciplinary knowledge*, *skills*, and *practices*; *Contexts*; *Dispositions*; *Tools; and critical orientation)* described for each of principals, teachers, students, and STEM education researchers.
STEMCrAfT	Science, technology, Engineering and Mathematics Critical Appraisal for Teachers
TEFL	Teaching for Effective Learning
WASCS	Western Australia Department of Education System Case Study

1 Executive Summary

1.1 Background

This report describes the processes employed and resulting outcomes of the Principals as STEM Leaders (PASL) project conducted from May 2018 to December 2020.

Principals are key to creating environments in which teachers can succeed in improving STEM learning outcomes within our schools. While there is an increasing array of resources that focus on developing STEM skills for both students and teachers, few specifically examine supporting principals as leaders of STEM education. To complement and ensure these resources are effectively harnessed, the PASL project developed a robust approach to supporting principals in driving whole-of-school collaborative efforts in enhancing student STEM engagement and learning outcomes. To this end, PASL focussed on building upon principals' leadership skills in a complementary manner with STEM capability, enabling effective STEM education leadership.

The objectives of the PASL project were to:

a. determine best-practice and expand evidence-based approaches that enhance student STEM engagement and learning outcomes through the professional development of principals as successful STEM leaders;
b. develop high quality and accessible resources (for example, for principals to
    - build their understanding of the concepts, skills and practices related to STEM disciplines,
    - lead initiatives promoting STEM teaching and learning, and
    - foster a STEM positive school culture);
c. support a 'critical friend model' to be made available beyond the life of the project; and
d. evaluate both the impact of the resources and the project processes and share lessons learned to inform future policy and practice.

PASL has produced a set of three evidence-based programmes of professional learning (PL) for principals, and STEM leadership teams, acknowledging their varying approaches to STEM education and aimed at developing their capabilities for leading school-wide and ongoing enhancement of STEM teaching and learning.

1.2 Funding context

PASL was funded by the Australian Government Department of Education, Skills, and Employment (DESE), under the Inspiring all Australians in Digital Literacy and STEM – Embracing the Digital Age initiative of the National Innovation and Science Agenda (NISA)[1].

1.3 COVID-19 as context for change

Through much of 2020, Australia experienced the COVID-19 pandemic, which impacted all aspects of society, not the least of which was the Australian educational system. In consultation with DESE, a revision of the timeline, PL schedule, and research design, as well as the repurposing of project team roles, was undertaken to accommodate the evolving challenges associated with the pandemic.

[1] See https://www.dese.gov.au/national-innovation-and-science-agenda

1.4 Brief summary of method

The PASL project consisted of three Work Streams using a mixed methods research design and incorporated both formative and summative evaluation across these Work Streams, as follows.

Work Stream 1:
Research to inform the development of PL modules and practices leading to principal STEM leadership capabilities.

Research, including identifying best practice STEM leadership approaches, drawing from a systematic review of recent Australian and international literature, a desktop audit and case studies of exemplary leadership and STEM education practice in Australian schools. These informed the development of PL modules and a supportive critical friend approach to PASL.

Work Stream 2:
Development of PL modules/resources and research into their impacts.

Three PL programmes were developed collaboratively with primary and secondary school principals, and school leadership teams, in Government, Catholic and Independent sectors across Australia. PL programmes drew on the findings of Work Stream 1, adaptation of aspects of the existing Principals as Literacy Leaders programme PL (PALL) and the expertise of STEM discipline and STEM education colleagues. Research data were collected on the impacts of principals' participation in the PL. These data informed the refinement of the PL and formed the basis of our recommendations for STEM leadership enhancement.

Work Stream 3:
Process monitoring and evaluation.

Over the life of PASL, the research project generated data that contributed to the monitoring and formative and summative evaluation of the conduct of the PASL research project. Findings from Work Stream 3 maximised the effectiveness of the project and informed the recommendations, especially as they relate to further development of principals' STEM capability.

1.5 Summary of findings from research

Data were generated through both quantitative and qualitative measures throughout PASL, from those participating in the PASL PL and where possible their teachers and students, and from principals, staff and students whose schools were selected as case studies. A fifth case study was purposefully selected as it provided a snapshot of a systemic approach to supporting STEM education; data for this case study were generated through interviews with key informants.

1.5.1 Quantitative Data: PL Participants

Survey data were gathered from principals participating in the PASL PL (34 schools) and 196 of their teachers. Where principals agreed, and both human ethics and time allowed, students (twelve participating schools) also participated in a survey.

All principals participating in the PASL PL survey indicated that STEM PL was their most highly valued priority. Prior

to their engagement in PL, principals expressed their keenness to improve STEM teaching and learning in their schools. This may explain the positively related factors measured prior to their PL and impacted their potential to change because of participating in the programme. COVID-19 may also have influenced their survey responses.

The data indicated that principals changed in the following ways across the time period in which they participated in PASL PL. Specifically, there was:

- an increase in principals' efficacy for transformational leadership;
- a decrease in principals' perceived difficulty of science; and
- a reduction in the reported need for PL related to leading STEM.

This Report presents survey results for 82 teachers of mathematics, 77 teachers of science, 21 design & technology teachers, 18 digital technology teachers, and 74 teachers of integrated STEM[2]

Key findings were:

- Teachers' perceptions of their principals' level of support or pressure was largely unrelated to either their instructional practice, or beliefs about mathematics or science.
- For science teachers only, their extent of external engagement (for example, with families, businesses, or tertiary institutions) promoted adaptive instructional practices, including teacher enthusiasm, inquiry learning, and providing academic challenge.
- For both mathematics and science teachers, confidence or self-efficacy for their own teaching abilities promoted their adaptive instructional practices. So too did their confidence to develop students' 21st Century skills. Teachers' collective efficacy beliefs (about their colleagues' abilities) was beneficial for mathematics, but not science.
- Mastery of goals to improve one's teaching positively related to adaptive teaching practices (teacher enthusiasm, academic challenge, inquiry learning, and for science teachers only, teacher-directed practices, such as facilitating class discussion, discussing student questions, providing explanations and demonstrating ideas).
- In mathematics, relational goals (such as caring for students) promoted data literacy and inquiry learning activities; there were no relationships for science.
- In mathematics, work avoidance goals (for example, reporting spending relatively little time preparing for lessons) were associated with reduced teacher enthusiasm; in science work avoidance goals were higher for teachers who found science to be more difficult.
- All measured instructional practices, except teacher-directed instruction, promoted students' curiosity in mathematics.
- All teaching practices measured promoted students' curiosity in science.
- Most importantly, for promoting student curiosity, was the level of academic challenge teachers provided.
- Teachers' own interest for mathematics/science was also foundational to their students' curiosity in both disciplines. Teachers who found mathematics/science more difficult, 'dampened' their students' curiosity.

1.5.1.1 Students

Student data (12 schools: six primary, five secondary, one combined) collection was limited due to the impact of COVID-19. It was impossible to collect planned second timepoint survey data, and for many other students whose principals joined the PASL study in 2020, it was not possible to collect the first student survey data. As a result, inferences drawn need to be interpreted with caution.

[2] Note: numbers do not sum to 196 as many teachers taught more than one STEM subject.

The data showed:

- an apparent decline in mastery climate (that is, a focus on individual goals and improvement rather than on competition), positive teacher expectations and relationship quality (teacher focus on building relationships with students) through secondary school;
- the promotion of academic challenge and curiosity occurred with low frequency in classes overall, regardless of grade level; and
- performance-focused classrooms that emphasise achievement and competition are sometimes positive, but frequently have harmful effects on dimensions of students' STEM engagement.

Neither inquiry learning practices nor the use of tools (for example, laboratory equipment and measuring instruments) seemed influential in promoting students' engagement and learning in STEM domains. While students tended to hold an incremental rather than a fixed or entity view about their abilities in each of mathematics and science, believing they could grow and improve; of some concern are their reported beliefs about mathematics and science including:

- on average, irrespective of grade level, students perceived boys to be better at both mathematics and science than girls;
- primary school students thought their peers valued both mathematics and science more so than secondary school students; and
- students also thought their peers were more interested in science than mathematics.

1.5.2 Qualitative Data: PL Participants

Data were generated via interviews with principals participating in PASL PL, and their teachers.

In relation to STEM discipline and integrated knowledge and practices, principals indicated that their involvement with PASL had clarified their understanding of STEM education and their roles as leaders of STEM education. They also reported deeper engagement with the challenges of interdisciplinary approaches to STEM education and the need to focus on developing staff capability rather than the acquisition of resources alone.

Principals reported they had become more aware of the importance of understanding their school's context. Their capacity to develop a vision for STEM education that all staff could communicate to the school community was identified as key to promoting a positive STEM culture.

Principals' dispositions towards generating a positive STEM education in schools was evident in their commitment to equity in developing every student's STEM capability, not just high achievers in science or mathematics.

Another important role for principals was the management of school resources – including the appropriation of STEM tools. In general, these tools were focused on digital tools (for example, robotic technologies) or school infrastructure (built environment). Principals reported that they had become more discerning over time, with a shift from considering the tool itself to how it would be used to promote problem-solving and critical thinking capabilities.

Principals indicated that they understood the need to take a more critical stance in relation to how they supported STEM education in their schools. This was particularly apparent in their decisions about how to introduce more integrated approaches to STEM education in their schools and in the use of data in decision-making.

The key aspects of PASL PL that influenced principals' thinking and/or reported actions in regards their development of a positive STEM culture in their schools related to six aspects addressed in the modules.

Specifically, principals reported:

- having developed a better understanding the nature of STEM;
- finding the STEM Capability Sets to be a useful organisational framework to structure their own thinking and for framing discussion of the development of a positive STEM culture with staff;
- PASL PL helped them to clarify their school's approach to STEM in relation to the Australian curriculum;
- PASL PL provided new perspectives on pedagogy, informing their approach to inquiry, scope and sequencing, and planning inquiry units, and highlighted considerations around assessment validity and priorities;
- PASL PL inspired new ideas about how they could incorporate the use of data in STEM activities, and how data could inform their school's direction in teaching, learning and assessment; and
- PASL PL was informative in relation to the structures necessary to support the construction of optimal teams to progress their STEM agendas, to create a STEM positive culture, to support the STEM learning specialists already in place and to build STEM supportive networks.

Findings from the teacher interview data largely aligned with those from the principal interviews.

In relation to STEM discipline and integrated knowledge and practices, teachers agreed that a focus on developing staff capability is key, rather than the acquisition of resources alone in support of STEM education.

Teachers endorsed the need to generate and promote a STEM education vision that was context-specific, informed by local needs as well as highlighting the importance of principals' confidence in teachers' capacity to support this vision and respect for their autonomy as professionals.

The importance of principals' dispositions resonated with teachers who recognised there is a risk that principals could distance themselves from the actual progress of schools' STEM education goals and indicated they believed the role of principals in STEM education was key.

Teachers supported the notion that the acquisition of STEM tools (resources) should not be an end in itself and that it was important that the purchase of STEM tools was connected to broader educational goals.

1.5.3 Case Study Findings

Findings from the four case study schools aligned well with the analysis of data from the survey and interviews with principals, teachers and students generated from PASL PL participants.

Key findings included:

- visionary and entrepreneurial leadership are essential to STEM education goals and developing a STEM positive culture within schools;
- principals were strategic and shared particular personal attributes that enabled them to lead, rather than having expertise in STEM;
- the creation of appropriate teams and STEM leadership positions is essential to supporting the vision for STEM education;
- inquiry-based learning drawing from interdisciplinary, authentic, relevant and student-led interests is a common approach to engaging in STEM learning;
- engaging with parents and stakeholders and achieving their support is essential to achieving STEM education goals; and

- the Australian curriculum and assessment requirements (and state syllabi) are perceived as unhelpful for teachers engaging with interdisciplinary STEM.

The system case study, undertaken with the Western Australian Department of Education, also resonated with other PL data generation and the findings from case study schools. Key findings included:

- system-wide success of STEM initiatives focussed upon building capacity through whole-school learning and development, namely:
    - professional learning and innovation strategy were closely aligned to school contexts in their design, participation and evaluation,
    - principals took part in learning processes with their leadership team members and teachers, and
    - focus was on improving pedagogical practices and assessment techniques to make them problem-based, challenging, and engaging for students;
- schools mentored other schools, rather than requiring individuals to mentor individuals;
- whole-of-school, principal-led communities of practice were vital for providing effective facilitation of innovation into the classroom;
- inquiry-based learning centred around real-world issues is valued by systems as a means of engaging schools in STEM education;
- learning-enriched STEM cultures can be achieved by bridging the gap between and connecting schools, community and industry; and
- school curricula must connect students with their real-world and their future prospects or interests.

1.6 Summary of findings from evaluation

The external and independent monitoring and evaluation of the conduct of the PASL research project through its lifetime provided the project directors, project team and DESE personnel with useful feedback which could be acted upon in real time. Barriers (such as lack of shared understandings) and facilitators (for example, commitment and collegiality of project team) to the implementation of PASL were communicated to the PASL directors regularly, enabling their timely action. Other than contributing to PASL-specific learning throughout its implementation, the PASL external evaluation has also resulted in a useful template/process for other future project teams seeking to evaluate the effectiveness and efficacy of their work in real time.

1.6.1 Key Findings From Principals Participating In PASL PL

The principals appreciated the quality of the professional learning and the opportunity for engagement with the presenters. While they felt it would be impactful, most agreed it was too early to determine the full impact of the project.

Participating in PASL required principals to both contribute data to the project themselves, and to also organise the collection of data from staff and students. Most principals agreed that while this was a short-term inconvenience, they understood the current and potential benefits of doing so was worthwhile.

Principals appreciated that PASL PL offered them the opportunity for very useful professional conversations and peer mentoring and learning. While many principals found the PL clusters to be a very rich learning experience, in some instances the cluster schools were not well matched, or the cluster was too small, or the geographic distances between schools was large, which made ongoing contact between participating schools difficult.

The critical friend model was designed to enable participating principals to have access to a person who is encouraging and supportive but also willing to engage in critical and constructive conversations about ways forward for STEM education in their school. While incorporating the critical friend model in the project research design was an innovation, it was not successful during implementation.

1.6.2 Key Lessons For Project Success

PASL team members had diverse and complementary professional experience and expertise and a strong shared commitment to the project outcomes. Inevitably, there were changes to team membership. Individuals changed roles and moved to different institutions and, in this regard, more attention should have been paid to induction processes as new members were added to the team.

The project directors and project manager met weekly and created a communication hub for the rest of the team. Team cohesion was supported by face-to-face meetings of key team members and regular online team meetings, both of which were very helpful for sharing information particularly when supported by a repository in the form of CloudStor.

The presidents of the national principals' associations were key team members, and their contributions brought a unique perspective to the team and helped to reframe situations from a deep understanding of the work context for principals. While their participation was invaluable, their availability was limited due to conflicting demands on their time.

1.7 Recommendations

The recommendations listed below are grouped in terms of the level of consideration of STEM capability development to which they apply and at which they can be implemented, from system level through to individuals and individual STEM classrooms. They are derived holistically from the combined survey, interview, and case study data gathered as part of the PASL project.

1.7.1 System Focus

1. Sustained funding is required for science and innovation, infrastructure, and equipment, and for building the capabilities of teachers to adopt appropriate pedagogical practices. Despite multiple STEM-related projects and substantial total funding, the reach of projects such as PASL which upon its conclusion requires voluntary engagement of individuals, is necessarily limited. The impacts of quality resources produced would be enhanced by facilitated roll-out and active dissemination.

2. More attention needs to be directed to schools from medium to low socioeconomic areas and disadvantaged communities, to provide principals with appropriate mentoring and access to resources and initiatives for the creation of equitable learning environments and an innovation culture.

3. The extent to which the curriculum is conducive to, or limiting of, STEM teaching and is influential towards the implementation of inquiry-based pedagogies that ensure students' learning is purposeful, interesting, and future-focused, requires further investigation.

4. For optimal success, national projects of this kind should include (as PASL did):

- cross-sectoral collaboration,
- an holistic formative, as well as summative, process evaluation,
- the involvement of the principal's associations,
- the development of quality documentation, and
- acknowledgement of the real challenges of managing the complexities.

5. Rigorous longitudinal research tracking the impacts of projects, including at the student level, is needed to strengthen the evidence base about effective STEM teaching, learning, leadership, and enhancement.

1.7.2 Community Engagement

6. Where possible, an emphasis on the school-community-industry partnership needs to be developed and presented as a regular feature of the curriculum, enabling a bidirectional flow of STEM understanding between industry and schools.

7. More support is required to assist principals to balance the demands of their school communities, and STEM education, and educational system and curriculum requirements, and to be able to communicate their STEM strategies effectively to their school communities.

1.7.3 Professional Learning Focus

8. Further investigation should be undertaken of the connections among teachers' STEM backgrounds, their beliefs and teaching practice, and elements of school climate and culture, and the resulting impacts on students as a basis of PL that is better targeted for teachers of different STEM subjects or integrated STEM.

9. The focus of PL requires attention to ensure that it assists principals and teachers to increase the academic challenge of STEM learning, focus on developing students' conceptual understanding and supports them to strengthen students' curiosity about STEM.

10. Professional learning programs for principals would benefit from a focus on the use of data in determining future strategic directions and how these decisions are communicated to teachers and the broader school community.

11. Professional learning is needed that is aimed at strengthening teachers' knowledge in STEM disciplines and hence their self-efficacy, interest, and enthusiasm for teaching STEM subjects.

12. Principals and STEM leaders would benefit from a greater understanding of the role of STEM tools (resources) in achieving the broader goals of STEM education, such as problem-solving and critical thinking.

1.7.4 Individual STEM Capabilities

13. The STEM Capability Sets or the dimensions that represent capability for STEM education and learning (Chapter 3) have been identified through this project as a useful way of working with principals and STEM leaders to assist them to understand how to create a STEM-capable school. Further research is recommended with the aim of:

    - further validating the Capability Sets;
    - determining how they might be used for professional learning purposes; and

- evaluating STEM capability at the levels of principals, teachers, students, and school communities.

14. Further research needs to be undertaken on the degree to which principals require STEM discipline-specific and technical knowledge capability, and the precise nature of that knowledge, to be effective in their various roles as decision makers in developing a positive STEM culture in their school's needs.

15. Greater attention should be paid to the development of positive dispositions towards STEM among principals, teachers, students, and school communities; to build parental awareness of the importance of STEM learning as relevant for all; and to acknowledge its various demands in principals' professional learning programs.

16. Principals, as well as their STEM leadership teams, should be directly involved in STEM PL and initiatives in their schools. This is crucial to effective STEM leadership; students understanding of and aspirations for future career paths in the STEM-associated fields relies upon principals, STEM leadership teams and teachers being aware of the opportunities and pathways towards their attainment.

1.7.5 Student STEM Learning

17. Further investigation of the impacts of pressure that principals apply to teachers in relation to student achievement in mathematics and science is needed, in addition to an investigation of how negative impacts can be mitigated.

18. Longstanding issues, such as students' perceptions that boys are better than girls at mathematics and science, that mathematics is less interesting than science, and the decline of student interest in mathematics and science from primary school to secondary school continues to require further and sustained attention.

19. Attention needs to be paid to increasing the extent to which STEM learning environments are experienced by students as intellectually challenging and fostering of curiosity.

2 Introduction

This chapter provides an overview of the PASL project research aims, objectives and design, a summary of the components of this report and a description of the PASL project governance processes.

2.1 Rationale for the PASL project

Science, Technology, Engineering and Mathematics (STEM) are acknowledged as key to national innovation and economic prosperity (Atkinson & Mayo, 2010; Kearney, 2011; Organisation for Economic Co-operation and Development [OECD], 2016a; Wienk, 2017). At the same time, there are concerns about the insufficient number of graduates from STEM related disciplines (Office of the Chief Scientist, 2014).

Efforts to address this issue have targeted increased student enrolment in STEM disciplines, improvement in the quality of STEM teaching (Avendano, Renteria, Kwon & Hamdan, 2019; Kearney, 2011) and enhancing student confidence in relation to studying STEM disciplines and consequently choosing a STEM career (Gilson & Matthews, 2019).

The Australian government has made significant investments in the development of resources to support STEM teaching, and particularly those teaching out-of-field (Australian Academy of Science, 2021; Department of Education, Skills and Employment, 2020; Fraser, Beswick, & Crowley, 2019a, 2019b; Geiger et al., 2018).

The PASL project was framed in recognition of the limited attention paid to the role that school leaders play in enhancing the teaching and learning of STEM, despite the acknowledgement of the importance of instructional leadership (Aas & Paulsen, 2019; Robinson, 2007). The systematic literature review (Chapter 4), conducted as part of PASL, revealed little was known about the extent to which instructional leadership is discipline specific.

2.2 Project overview

This section describes the three Work Streams that comprised the PASL project. Although Work Stream 1 could be commenced prior to the other Work Streams, it continued simultaneously with both Work Streams 2 and 3. The three Work Streams were thus mutually informing as PL resources were created, trialled, and iteratively refined. The approach to each Work Stream was underpinned by the theoretical framework outlined in Chapter 4.

2.2.1 Work Stream 1: Research to inform the development of PL modules and practices leading to principal STEM leadership capabilities

The purpose of the research in Work Stream 1 was to ensure that the PASL project resources were founded on current understandings of best practice in leadership of education in STEM. Research conducted in Work Stream 1 was structured around the STEM Capability Sets described in Chapter 3.

The STEM Capability Sets informed all elements of the project. Work Stream 1 drew from three sources:

1. a systematic review of recent literature related to education in STEM;
2. a desktop audit of recent and current STEM education initiatives and resources; and

3. Case studies of exemplary leadership and STEM education practice in schools.

2.2.2 Work Stream 2: Development of professional learning modules/resources and research into their impacts

A set of three programmes of professional learning[3] aimed at developing the capabilities of principals for leading school-wide ongoing enhancement of STEM teaching and learning were developed and evaluated in this Work Stream. The PL modules include detailed facilitator notes that allow modules to be delivered by appropriate systems, schools, and leaders after the conclusion of the project, or to be used by individual principals interested in developing aspects of their STEM leadership capability.

The foci of the three programmes were as follows:

Programme 1: Leading quality STEM teaching and learning
Programme 2: Whole of school development through STEM
Programme 3: Equity, diversity, aspirations for, and sustainability of STEM initiatives

A more detailed description of the intent of each programme and an overview of the modules that constitute each is provided in Chapter 4. The programmes were trialled in diverse settings and made use of a range of delivery modes as described in Chapter 3. This latter chapter also includes details of the research design and data collection used to investigate the impacts of the PL.

2.2.3 Work Stream 3: Process monitoring and evaluation

Monitoring and evaluation was conducted throughout the life of the project in relation to two aspects of the research project:

- the PL programmes, modules, resources and supporting critical friends approaches for principals; and
- the conduct of the PASL research project.

Monitoring and evaluation processes informed the adjustment of project implementation strategies to accommodate the changing educational context. Processes were designed to provide feedback that was specific, timely and related to project goals. Resulting recommendations targeted the improvement of project implementation.

A formative evaluation methodology was developed to provide feedback on project implementation and the achievement of outcomes at intermediate stages of the project. The evaluation team engaged with principals, team members, members of the reference group and DESE professional officers to facilitate a cycle of feedback and review aimed at optimising the achievement of the project goals.

Details of the evaluation methodology and its outcomes are provided in Chapter 8.

[3] A 'professional learning module' refers to an episode of learning that could be delivered over a period of one to three hours. A 'programme of professional learning' refers to a coherent sequence of at least six such modules.

2.3 Impacts of COVID-19

At the end of 2019 and throughout 2020, Australia experienced the COVID-19 pandemic, which impacted all aspects of society, including the Australian educational system. Impacts on the PASL project related to recruitment of participants, scheduling of PL, and limitations on data collection. There was a greater reliance on online PL delivery.

2.4 Chapter overview

Chapter 1 provides an executive summary of the project and lists recommendations from PASL research. This chapter, Chapter 2, provides an overview of the PASL project including its rationale, structure and governance. In Chapter 3 the theoretical underpinnings of the PASL research design into the impacts of project PL are described in addition to details of the data collection methods that were employed. Chapter 4 describes findings from the literature review and desktop audit that informed the development of PASL PL programmes. The development process and foci of all three PASL PL programmes and their modules are also described Chapter 4.

The findings of the PASL project are presented in Chapters 5, 6 and 7. Chapter 5 describes the survey findings in relation to aspects of STEM capabilities of principals, STEM teachers, and students. Findings from the interview data about the impacts of principals' participation in PASL PL programmes on their STEM leadership capabilities are presented in Chapter 6, and Chapter 7 provides findings from the case studies including a cross-case analysis.

The final two chapters, Chapters 8 and 9, discuss PASL's approach to evaluation and the findings from that process, while Chapter 9 summarises the outcomes and impact of the PASL project on school leadership of STEM.

Following a List of References, the Appendices comprise (A) Survey Description of Measures and Descriptive Summaries, (B) Research Instruments and (C) COVID-19 Context Response.

2.5 Team membership

The PASL project is a consortium of partners, led by the University of Tasmania. Three directors from the University of Tasmania, the Australian Catholic University and the University of New South Wales oversaw the project with team members representing Macquarie University, University of Sydney, University of Queensland, University of Notre Dame (Australia), and Flinders University. An Evaluation Manager was subcontracted to progress Work Stream 3 (project evaluation). The inclusion of leaders from the two national principal associations (APPA and ASPA) as project team members aligns with the underlying philosophy of collaboration and co-construction, and is key to decision making and liaison with school principals.

2.6 PASL Reference Group

The Project Reference Group (RG) was established to provide advice and support for PASL, including the implementation of its findings. The responsibilities of the Project Reference Group were to:

- Provide advice on:
  - the project plan and method;
  - the desktop review of existing STEM initiatives;
  - the survey instruments, questionnaires and tests; and
  - results and reports.

- Assist in providing information to the Project Team on national, state and territory, and sectoral STEM initiatives.
- Assist with school selection and facilitation of access to schools within their jurisdictions and education sectors, and associated ethics clearances, where relevant.
- Promote the study and its findings within their jurisdictions, organisations, and associated schools.
- Provide advice that contributes to the development of a strategy for the implementation of best practice (based upon the findings) in STEM education.
- Provide insights and advice about the context within which PASL will be implemented relevant to their constituents.

The reference group was co-chaired by Dennis Yarrington and then Malcolm Elliott, Presidents of APPA, and Andrew Pierpoint, President of ASPA, respectively. Membership comprised stakeholders drawn from state and territory and systemic jurisdictional bodies responsible for STEM education, and from membership associations and industry groups with significant involvement in and responsibility for STEM education and leadership (full institutional membership is shown in Table 1).

The reference group was governed by the terms of reference developed with the funder and ratified by group members at the first meeting. Prior to the COVID-19 pandemic, the group met at least twice annually, with one of those meetings held face-to-face with a quorum of at least eight members. In 2020, the reference group was able to meet only once towards the end of the project, as the first meeting of the year was cancelled due to the impact of COVID-19.

Table 1: Reference group membership

ORGANISATION
Aboriginal and Torres Strait Islander Mathematics Alliance
Association of Heads of Independent Schools of Australia
Australian Academy of Science
Australian Association for Mathematics Teachers
ACT Education Directorate
Australian Council for Computers in Education
Australian Council of Deans of Education
Australian Council of Deans of Science
Australian Industry Group
Australian Institute for Teaching and School Leadership
Australian Maths Sciences Institute
Australian Science Teachers Association
Australian Special Education Principals Association
Catholic Secondary Principals Association
Commonwealth Scientific and Industrial Research Organisation
Department of Education, Skills, and Employment
Independent Schools Council of Australia
National Aboriginal and Torres Strait Principals Association
National Centre for STEM Education at the University of Limerick, Ireland
NSW Department of Education
QLD Department of Education
SA Department for Education
TAS Department of Education
VIC Department of Education and Training
WA Department of Education

3 Research design and methodology

3.1 Introduction

This chapter begins with a description of the theoretical underpinnings of the PASL project, encapsulated in the STEM Capability Sets. This framework provided a foundation for the design of the PL and the research investigating its impacts. Section 3.2 is followed by a description of the research design and methodological approach.

3.2 STEM Capability Sets

The STEM Capability Sets underpinned all aspects of the PASL project. Development of this framework drew on the 21st century model for numeracy (Goos, Dole & Geiger, 2012, Goos, Geiger & Dole, 2010). STEM capability was conceptualised as comprising four inter-related dimensions:

- STEM discipline-specific and interdisciplinary knowledge, skills, and practices,
- Contexts,
- Dispositions,
- Tools,

with a Critical orientation considered an essential overarching dimension (see Figure 1).

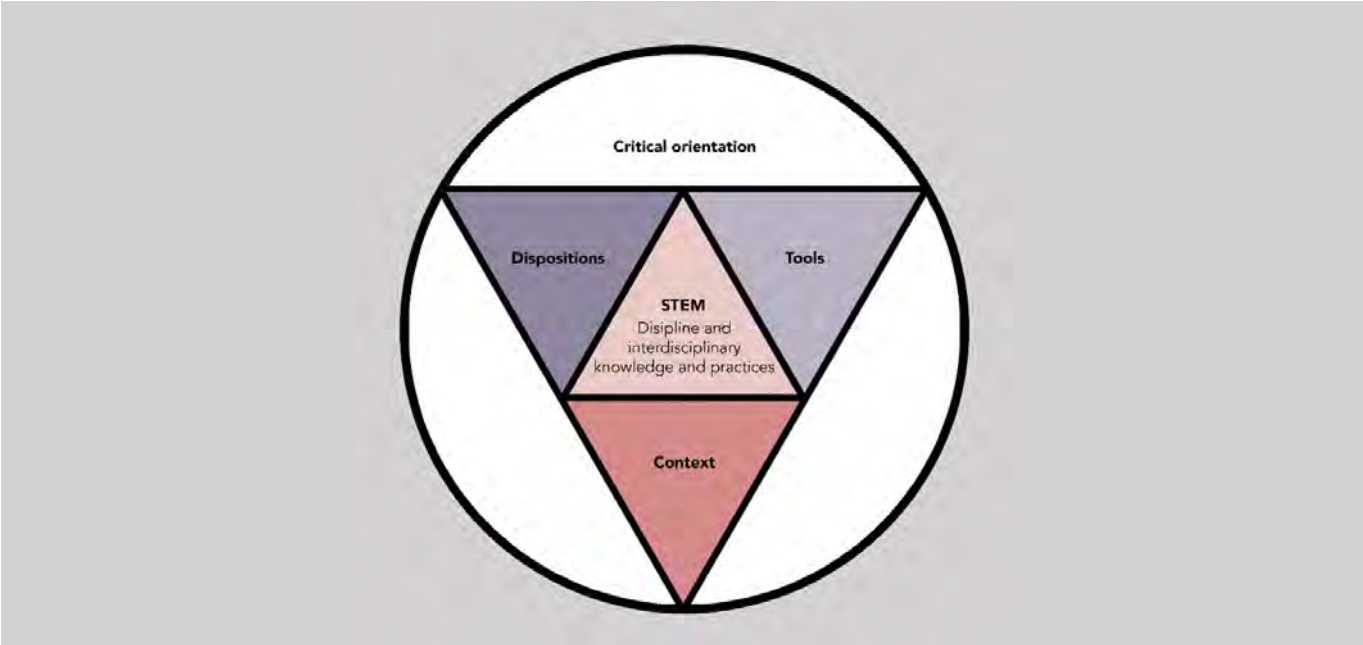


Figure 1: STEM capability conceptualised as comprising four inter-related dimensions

© 2017 Australian Catholic University and University of Tasmania. CC BY-NC-ND 3.0 AU. The framework is adapted, and draws on information from a model of numeracy for the 21st century from: Goos, M., Geiger, V. & Dole, S. (2010). Auditing the numeracy demands of the middle years curriculum, and Goos, M., Dole, S. and Geiger, V. (2012). Auditing the numeracy demands of the Australian curriculum. Used with permission. © 2010, 2012. Mathematics Education Research Group of Australasia (MERGA).

The dimensions of STEM capability were initially described for each of principals, teachers, students and STEM education researchers. As a result of feedback during the project, an additional Set was developed for school community members. The model was tested and further refined throughout the project. This process validated the efficacy of the framework as a framework for PASL PL and as a structuring element for the design of research activities. Our initial findings indicated the STEM Capability Sets have potential for application in contexts beyond work with principals. As an example, a description of each of the dimensions of STEM capability for principals is provided in Table 2.

Table 2: STEM capability for principals

STEM CAPABILITY DIMENSION	CAPABILITY INDICATORS
STEM DISCIPLINE-SPECIFIC AND INTER-DISCIPLINARY KNOWLEDGE, SKILLS AND PRACTICES	• Awareness of concepts, skills and practices related to STEM disciplines. • Awareness of the range of careers that require STEM skills and the role STEM plays in both individual well-being and national economic growth. • Knowledge of relevant components of the Australian Curriculum and national policy documents. • Capacity to lead initiatives aimed at promoting STEM teaching and learning (for example, teacher professional learning groups and connections to industry). • Capacity to foster a STEM-positive school culture (positive student, teacher and parent attitudes towards STEM education).
CONTEXTS	• Capacity to develop a vision for whole school STEM teaching and learning relevant to specific educational environments. • Capacity to promote STEM education to the broader school community and manage associated expectations. • Strategic in managing the demands and opportunities associated with national and state curriculum and policy requirements and settings. • Capacity to establish partnerships (for example, with industry, business, or tertiary institutions). • Capacity to lead sustainable educational change specifically allied to the culture of the school.
DISPOSITIONS	• Belief that all students and teachers can develop/enhance their STEM capability. • Openness to the implementation of innovative STEM teaching practices. • Confidence that innovative STEM programmes can be initiated, managed and brought to fruition. • Flexible and adaptable change leadership practices so that all feel supported and encouraged during their engagement with STEM project regardless of differences in levels of knowledge, skill and confidence. • Willingness to be personally and actively involved in establishing and sustaining school STEM teaching and learning programmes. • Flexible and adaptive thinking as their school continues to innovate (for example, openness to changes in school curriculum delivery structures and practices).

TOOLS	• Understanding of the role physical tools (such as models and measuring instruments), representational tools (for example, symbol systems, graphs, maps, diagrams, drawings and tables) and digital tools (computers, robots and Internet of Things) play in STEM teaching and learning. • Capacity to identify and procure resources that support effective STEM teaching and learning within their school context.
CRITICAL ORIENTATION	• Preparedness to make evidence-informed judgements and decisions about whole school STEM teaching and learning programmes. • Capacity to gather and analyse relevant data to inform future directions in promoting STEM teaching and learning. • Extensive knowledge, skills and capacities related to leading complicated educational change effectively.

STEM capability sets (Geiger, Beswick, and Fraser, 2017). © 2017 Australian Catholic University and University of Tasmania. CC BY-NC-ND 3.0 AU. The framework draws on information with permission from a description of elements of the Numeracy Model from: Goos, M., Dole, S. and Geiger, V. (2012). Auditing the numeracy demands of the Australian curriculum. Used with permission © 2012 Mathematics Education Research Group of Australasia (MERGA).

STEM capability for each of principals, teachers, students, school community and STEM education researchers was conceptualised as a system of bi-directional cascading interactions (as shown in Figure 2).

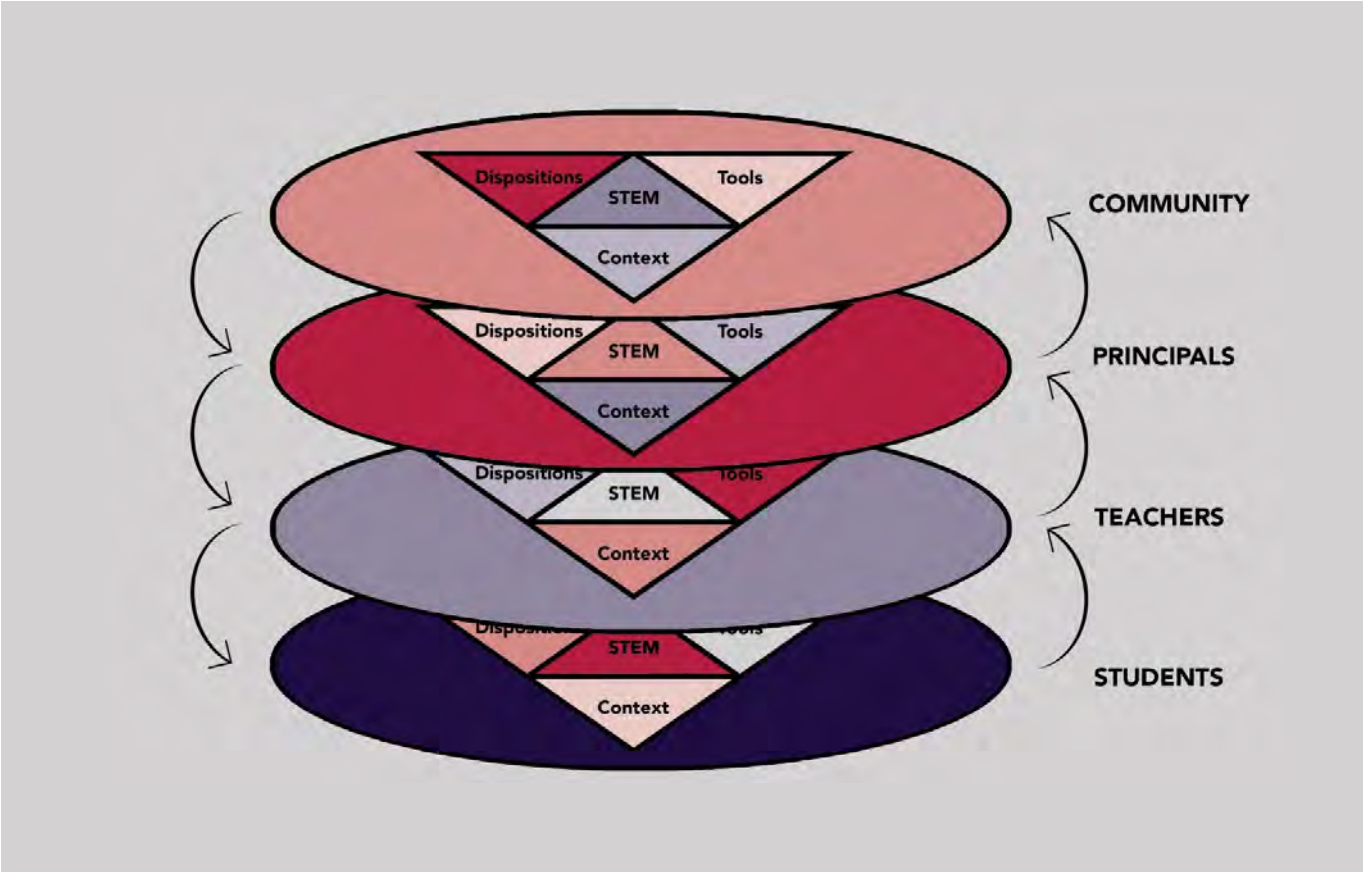


Figure 2: STEM capability cascading sets graphic (Geiger, Beswick, and Fraser, 2017)

© 2017 Australian Catholic University and University of Tasmania. CC BY-NC-ND 3.0 AU. The framework is adapted, and draws on information from a model of numeracy for the 21st century from: Goos, M., Geiger, V. & Dole, S. (2010). Auditing the numeracy demands of the middle years curriculum, and Goos, M., Dole, S. and Geiger, V. (2012). Auditing the numeracy demands of the Australian curriculum. Used with permission. © 2010, 2012. Mathematics Education Research Group of Australasia (MERGA).

It is important to note that the ordering of layers in Figure 2 does not imply a hierarchical connection between them; rather, academics, such as those involved in the PASL project, were seeking to support the development of principals' STEM capability. Principals, in turn, would play an important role in the development of STEM capability among teachers in their school. Teachers are then positioned to facilitate learning that allows students to develop their STEM capability. This activity can be enhanced, or inhibited, by the support (or otherwise) afforded by the school community.

The STEM Capability Sets underscores the ambition of the project and the complexity of the principals' role as STEM leader.

3.3 Research design and methodology

The research design and methodology for the project is outlined in the following section, including descriptions of the design, data collection instruments and target participants, literature review and desktop audit.

The project was designed to pilot PASL PL in as wide a range of school contexts as possible, including fully face-to-face, fully online and blended modes.

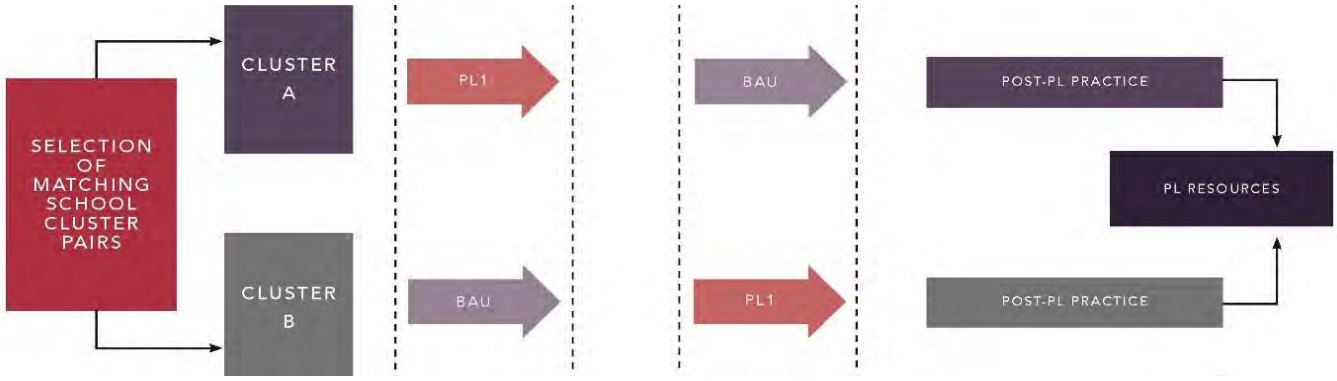
3.3.1 Design

The intent was to pilot each PL programme in two clusters of three to six schools in each of the following states/regions (n=7): TAS, VIC, NSW/ACT, SA/NT, WA, QLD, and far north QLD (FNQ). The two territories, ACT and NT, were linked with the state with which they have closest ties in terms of curriculum. The clusters in FNQ were intended to include schools with high proportions of Indigenous students led by Indigenous principals. The selection of clusters was done to ensure:

- the inclusion of government, Catholic and Independent schools;
- the inclusion of schools with a range of ICSEA scores;
- varying degrees of rurality and remoteness; and
- a range of transition points (for example, ECE-primary, primary-secondary, secondary-senior secondary and secondary-post-secondary).

As shown in Figure 3, pairs of school clusters were matched as closely as possible in terms of ICSEA, number of enrolments, rurality, state and system, commitment of the principal to whole school STEM improvement (as evidenced by willingness to participate in the trailing of PL), and PL delivery mode (face-to-face, online, blended) to facilitate rigorous evaluation of the effectiveness of the PASL PL and associated resources and processes. The PL would be conducted first in one cluster from each pair, Cluster A, and subsequently in the second cluster of each pair, Cluster B, (cross-over design), with the second clusters acting as 'business as usual (BAU)' comparators prior to receiving the enhanced PL programme subsequently.

The design in Figure 3 was to be repeated in each of the seven regions, allowing each PL programme to be piloted in and adapted for diverse contexts. Each PL piloting period involving a pair of clusters was to last for approximately six months (two school terms – one term for PL in each cluster of each pair). The intention was to measure medium- and longer-term impacts of the PL through data collections at approximately six-monthly intervals following each piloting period.



PL: Professional learning BAU: Business as usual

Figure 3: PL impact research design

The crossover design shown in Figure 3 allows any changes observed in the cluster undertaking the PL to be compared with changes in a similar (matched) cluster not undertaking the PL. The more similar the pairs of clusters, the stronger the evidence that any differences in changes are the result of participation in the PL. The second cluster received the PL one term later and benefited from any refinements to that PL based on the experience with the first cluster. For both clusters, the follow up data collections were designed to allow the longer-term impacts of the PL to be discerned. It was likely that changes from the beginning to end of participation in the PL would only be at the principal level (such as changes in efficacy in relation to STEM leadership and plans for new ways of working). Longer-term changes could concern teachers and ultimately students in accordance with the cascading model of STEM capability depicted in Figure 2.

In terms of the refinement of the PL, the methodology was essentially Action Research, with principals generating data, alongside and contributing to project data, thereby enhancing their own critical reflection and data literacy capabilities.

As a result of the impact of COVID 19, the cross-over design and cluster formations were abandoned for data collection and trialling across Programmes 2 and 3. Only very limited longitudinal data on the impacts of Programme 1 could be collected. The revised design grouped principals available and willing to participate in the PL within their own states across Terms 2 and 3 of 2020.

An intent of the project was to offer a critical friend to work with principals to assist them in implementing their learning and developing within school processes for monitoring impacts of changes and reflecting on the effectiveness of initiatives. Critical friend arrangements were intended to be tailored to the contexts and needs of principals and clusters in terms of principals' experience, proximity to collegial support, school community contexts. This aspect of the project was not taken up to any great degree by participating principals early in the project and was abandoned as part of re-prioritisation necessitated by COVID-19. Nevertheless, there were findings from other aspects of the research (that is, case studies) in relation to critical friends that can inform future work of this type (see Chapter 7).

3.3.2 Data Collection Instruments and Participants

Data were collected via:

- surveys (principals, teachers, students from Year 4 to Year 12;
- individual interviews (principals and teachers);
- school case studies, involving interviews, artefact collection and lesson observations; and
- one case study focussed on systemic support for school-based STEM improvement, involving interviews.

Data were collected with ethics approval from the University of Tasmania[4], and approvals from Australian State/Territory governing ethics boards[5].

The surveys and principal/teacher interviews were designed to evaluate impacts of the PL and were aligned with the STEM Capability Sets (see Section 3.2) to ensure data that would enable valid conclusions to be drawn about STEM capability. Understandings of 21st century skills (specifically collaboration, communication, innovation and creativity problem solving and responsible citizenship) and their development through engagement with STEM learning were also explored.

3.3.2.1 Surveys

Survey instruments for principals, teachers, primary and secondary students were based on existing validated instruments that had been used previously by team members (Beswick, Watt, & Geiger). Original scales and items related to specific STEM disciplines, predominantly mathematics, were adapted to cover the four individual STEM disciplines and integrated STEM. Principals responded to a range of self-report measures regarding themselves, their leadership practice, school culture, and beliefs about each of mathematics, science, design & technology, digital technology, and integrated STEM. Constructs measured by that survey are listed below. (Detailed descriptions of each construct are provided in Appendix A.1).

- *Personal qualities (Time 1 only)*: openness, extraversion, conscientiousness, agreeableness, and neuroticism; priorities for future investment.
- *Leadership style*: transformational leadership, instructional leadership, support and pressure, data literacy, collecting / responding to feedback, personal involvement, need for PL.
- *School engagement*: identification with school, external engagement.
- *School culture*: collaborative teams, goal orientation, collective efficacy.
- *STEM beliefs*: intrinsic/utility/attainment values, perceived difficulty for each of mathematics and science.
- *STEM practical applications*: beliefs about tools, 21st Century skills.
- *Personal wellbeing[6] (Time 1)*: life satisfaction, emotional exhaustion, depersonalisation.

Teachers responded to measures of the constructs that are listed below. The online survey allowed only items

[4] Ethics Application Approval Number H0017470.

[5] **ACT**: Education and Training Directorate. **NSW**: Department of Education; Catholic Education Offices - Wagga Wagga, Wollongong, Armidale, Bathurst, Broken Bay, Maitland-Newcastle, Parramatta. **QLD**.: Queensland Department of Education; Catholic Education Offices – Brisbane, Rockhampton, Cairns, Townsville. **VIC**.: Department of Education and Training Victoria; Catholic Education Offices - Melbourne (CEOM), Sale, Ballarat, Sandhurst. **WA**: Department of Education; Catholic Education Western Australia. **SA**: Department for Education and Child Development (DECD); SA Catholic Education (Adelaide & Pt Pirie). **TAS**: Tasmanian Department of Education ; Tasmania Catholic Education. **NT**: Department of Education.

[6] Wellbeing items were only permitted in NSW schools and were not included in the analysis.

relevant to the STEM areas that teachers indicated they taught to be displayed.

- *Teacher attitudes towards STEM disciplines:* teacher beliefs – fixed or learned.
- *Teacher instruction in relevant STEM disciplines:* extent to which teachers academically challenged their students; enthusiasm for teaching; data literacy activities; and inquiry learning and teacher directed learning.
- *School culture:* principal support, external engagement.
- *Perceived efficacy:* self-efficacy in STEM subjects, STEM 21st Century skills, collective efficacy.
- *Teachers' goals:* goal orientations – mastery goals, work avoidance goals, relational goals.
- *Student engagement in mathematics and science:* curiosity.

Students responded to a range of self-report measures regarding STEM, specifically in relation to mathematics, science, technology (primary)/design & technology, digital technologies (secondary), and integrated STEM (secondary). STEM-specific questions were allocated to students dependent on their grade levels, as follows:

- *Years 4 & 5*: these younger students were randomly allocated questions on only one of mathematics, science, or technology; and
- *Year 6*: Year 6 students were asked parallel questions in relation to each of mathematics and science.

In the case of secondary school students, the following applies:

- students studying integrated STEM were asked those questions, additional to either mathematics or science (randomly allocated);
- students studying only one STEM subject were asked questions only in relation to that subject;
- students studying two STEM subjects were asked parallel questions relating to both; and
- students studying three or more STEM subjects were randomly allocated questions relating to two of those subjects.

Secondary students were additionally asked questions about their STEM-related career aspirations and 21st Century skills.

The STEM-specific questions tapped into several key constructs (described in full in Appendix A.5):

- *Perceived socialiser beliefs*: sex-typing, perceived peer value (mathematics/science only).
- *Theory of intelligence*: entity (fixed) versus incremental (growth) beliefs (mathematics/science only).
- *Motivations*: perceived talent, values, costs, and achievement goals.
- *Learning environments*: mastery and performance climate, teacher enthusiasm, academic challenge, curiosity.
- *Classroom practice*: inquiry learning, teacher-directed learning, teacher support, data literacy, use of tools.
- *Student-perceived teacher beliefs*: expectation, difficulty, value, relationships.

3.3.2.2 Semi-structured interviews

Semi-structured interviews were conducted with principals and teachers who had a STEM leadership role within schools (for example, middle leaders or STEM coordinators). Interviews included questions related to:

- the school and STEM;
- classroom practice (pedagogy, assessment, curriculum, equity, school environment, reporting, systemic supports, a classroom scenario);
- leadership; and
- following the onset of COVID-19, two questions were added that explored the impacts of the pandemic on STEM programmes.

A focus of these interviews was on principals' perspectives of the effectiveness of PASL PL programmes. Principals were also asked if and how PASL PL programmes had challenged or changed their thinking in relation to STEM education, especially in relation to developing and maintaining a positive STEM culture in their schools. The Principal Initial Interview Protocols are provided in Appendix B.2.

Principal and teacher interviews were scheduled to occur at four timepoints during their engagement with the project. Some teacher participants had school-level responsibility for STEM or one of its constituent disciplines. These participants are referred to as 'STEM leadership' in Tables 3 and 4. Interviews were conducted at times that suited the participants.

The focus and scheduling of semi-structured interviews are presented in Table 3.

Table 3: Focus and scheduling of semi-structured interviews

PARTICIPANTS	PRIOR TO PL PILOT	AFTER PL PILOT POST PL: 6 MONTH INTERVALS
PRINCIPALS	Individual Interview; school level planning documents relevant to STEM; work samples and images	Individual interview; evaluation interview; school level planning documents relevant to STEM; work samples and images
STEM LEADERSHIP	Individual Interview; area level planning documents relevant to STEM; work samples and images	
STEM TEACHERS	Individual Interview; work samples and images	

3.3.2.3 Case studies

The purpose of the case studies was to document innovative and effective leadership of school-wide teaching and learning practice in STEM education. The PASL project originally planned to identify case study schools from each region (inclusive of each state/territory) across Australia (n=7), however, due to the impact of COVID-19, only four case studies of schools were possible. A fifth case study, selected purposefully to document a system-wide approach to support STEM teaching, learning and leadership, was undertaken in Western Australia.

Case study schools were selected on the basis of nominations from systems – state, Catholic, Independent – as innovative designers and enactors of STEM active curricular. The four case studies schools were:

- Cerdon College (CC), New South Wales;
- Australian Science & Mathematics School (ASMS), South Australia;
- Hagley Farm Primary School (HFPS), Tasmania; and
- Brookman Primary School (BPS), Western Australia.

These schools represent a range of demographics; for example, high and low SES, metropolitan, Government, Catholic and Independent, rural and remote, primary and secondary. The case studies documented innovative and effective leadership of school wide teaching and learning practice in STEM education that may not have been captured by other aspects of the project. Additionally, the case studies provide a 'what is possible' insight into whole of school, principal-led STEM education as this is mediated by the specifics of school educational environments. The diversity of school case studies will enable resonance for the following:

- *Location* – a range of capital city, regional, rural and remote schools.
- *System* – including Government, Catholic and Independent.
- *School type* – single sex, as well as primary/secondary schools.

Data collection for the case study schools was conducted by members of the PASL project team residing in the same state as the school. Each case study involved at least a two-day visit to the school. Table 4 shows the data collected from various participants in the school case studies.

Table 4: Case study data collection methods

PARTICIPANTS	DATA COLLECTION (1-2 DAYS IN CS SCHOOL)
PRINCIPALS	- Individual Interview - School-level planning documents relevant to STEM - Work samples, curriculum planning documents and images
STEM LEADERSHIP	- Individual Interview - Area level planning documents relevant to STEM - Work samples and images
STEM TEACHERS (UP TO FOUR PER CS SCHOOL)	- Individual Interview - Lesson observation of at least one STEM lesson per CS - Work samples and images
STUDENTS	- One to three focus group interviews with up to five students each group (Years 5-6; 7-8; 9-10; 11-12), where applicable in each school - Lesson observation of at least one STEM lesson per CS school

The interviews were designed for principals, STEM leaders and teachers of STEM. The principal initial interview protocol is provided in Appendix B.2. Questions in the interviews focussed on STEM and its:

1. learning and teaching,
2. school organisation,
3. professional learning experiences for teachers and principals,
4. relevant policies such as homework and reporting,
5. its relevant available resources, and
6. teaching approaches, and beliefs about it.

All interviews were audio-recorded and transcribed by project support staff. Participants were attributed a pseudonym at this time.

Lesson observations were conducted in order to understand teachers' STEM teaching practices and how these might contribute to a positive and innovative STEM culture. Specific observations included:

- the main features of the lesson content and pedagogies employee;
- alignment with appropriate curriculum;
- alignment with; and
- use of physical resources in the school that enhance STEM culture (for example a particular piece of equipment or custom STEM space).

In the focus groups, the researchers asked students questions about how they experience STEM teaching and learning in their class(es) and at their school in general. The questions were designed to identify the good things that are happening in the school and not focus on negative experiences.

The researchers were also able to tour the school and its environs to view facilities and resources firsthand.

Once case study school data collection was complete, researchers created a case study school report, which was sent to the principal of the relevant school for checking, suggesting amendments and the removal and/or addition of text.

Chapter 7 provides a summary of each case study and a cross-case analysis of the set of case studies, highlighting aspects of exemplary practice that are pertinent to individual cases or shared across cases. The cross-case analysis identifies aspects of the schools' practices in STEM education that are critical, revealing and/or unique in some way (Yin, 2014), in order to highlight commonalities and differences across the schools.

A fifth case study was conducted within a state-based educational system, the Western Australia Department of Education. This case study was purposefully selected to enable an exploration of a systemic approach to developing and supporting the leadership of STEM within and across schools throughout ongoing professional learning, and the benefits of such a whole of system approach to mentoring, analogous to the provision of critical friends for school leaders.

3.3.2.4 Systematic literature review

The professional learning resources developed, trialled, and evaluated as part of the PASL project were underpinned by a systematic review of research literature related to the role of principals in enhancing STEM outcomes in their schools. The methodology used ensured that the review was both comprehensive and unbiased. It covered peer-reviewed research outputs published from 2000-2019 in Australia and internationally. The research team did not filter results according to the way in which STEM was conceptualised (that is, discipline-specific versus integrated) with the focus on the principal's role in promoting STEM education in all formats.

3.3.2.5 *Desktop audit*

A desktop audit of recent and current Australian STEM education initiatives was conducted to both inform the development of PASL resources for principals and to provide a database of practical resources for principals and their teachers. An additional aim of the desktop audit was to provide an evidence base for the development of policy and direction for effective initiatives in STEM education. The analysis of the identified initiatives may assist funding bodies to better understand the gaps in STEM education initiatives at state and/or national level.

3.3.2.6 *'Critical Friend'*

A goal of PASL was to recruit collaborating principals and mentors using the networks of the project team, particularly the principals' associations, participants, and the PASL Reference Group and system jurisdictions. Principals had the choice of nominating their own critical friend or being assigned one by PASL. Programme 1 and 2 participants were offered the services of a critical friend by the state team leaders and PL facilitators. For Programme 2 and 3, critical friends were additionally drawn from participating Programme 1 principals who expressed their ongoing commitment to PASL.

The project team had identified critical friends who had expressed their interest in participating in the programme; however, the take up for individual or group critical friends was minimal. Across the PL delivery and data collection, principals indicated fledgling interest in the critical friend programme.

The critical friend programme development and trialling was abandoned in early 2020 due to the impact of COVID-19, and for its lack of interest from participants. PASL further acknowledges that the communication around critical friend recruitment and matching processes required more concerted effort and monitoring. It is important to note that PASL provided principals with the opportunity to network with colleagues, which can be viewed as a benefit of their participation.

The project team considered research into the efficacy of critical friends/mentoring models critical to STEM leadership development. Drawing on the advice of the PASL reference group, the project team gained some insights through developing a case study with the Western Australia Department of Education, whose leadership and mentoring models in educational leadership were well established. (The WA Department of Education system case findings are described in Section 7.3, and the WA System Case Study Interview Questions are in Appendix B.11).

3.3.2.7 *External formative project evaluation*

A method of formative evaluation was developed to provide feedback on project implementation and the achievement of outcomes at intermediate stages of the project. The evaluation team engaged with principals, team members, members of the reference group and the DESE professional officers to facilitate a cycle of feedback and review to enhance achievement of the project goals. In contrast to a summative evaluation, the focus of the formative feedback was to support and develop the capability of the project team and the effectiveness of the intervention, rather than make a final judgment about achievement. Implementation evaluation of an educational research project is not commonly reported in the literature, but was viewed by DESE as a key aspect of the project. The eight aspects of implementation adapted for the PASL project are as follows:

1. *Integrity:* the extent to which the intervention adheres to the proposed programme.
2. *Coherence:* the extent of collaboration between key stakeholders to achieve project goals.
3. *Quantum:* the amount and scope of the professional learning delivered.
4. *Quality*: the relevance, currency and accessibility of the professional learning.
5. *Engagement*: the extent to which participants valued and acted upon the professional learning.

6. *Innovation*: the unique nature of the project and the degree to which it could be differentiated from other programmes.
7. *Reach*: the extent to which the participants and exemplar case studies are representative of the target audience.
8. *Adaptation*: the ability of the project team to respond to feedback and adapt to changing conditions.

An external and independent evaluator undertook the formative evaluation of the project. The external evaluator attended the initial project launch and team meetings through the duration of the project. An evaluation timeline was developed in consultation with the project directors and manager that ensured regular feedback and incorporated the views of team members, participating principals, members of the project reference group and, then later, the professional officers from the funding body. The main data collection strategy was semi-structured interviews conducted over the phone.

Importantly, the interview questions addressed all eight aspects of implementation and identified barriers and facilitators to implementation. Interviews with the principals (32) focused on:

3. *Quantum*,
4. *Quality*, and
5. *Engagement*.

The interviews with team members and DESE professional officers addressed all aspects of implementation. Team members were interviewed twice, with 14 interviews conducted in the first round and 20 in the second. The three professional officers of the funding body were also interviewed twice. The interval between the two interviews for the project team and the professional officers was 12-18 months.

A sample of six members of the Reference group was interviewed, and the questions focused on:

1. *Integrity*,
2. *Coherence*, and
6. *Innovation*.

4 Building STEM Leaders knowledge: Professional Learning Modules

4.1 Introduction

The PASL project developed a suite of PL programmes focussed on enhancing principals' understanding of the concepts, skills and practices related to STEM education. Programme design and development were informed by the findings of the PASL systematic literature review and desktop audit.

The modules were developed by the PASL project team and trialled with principals in both face-to-face and synchronous online modes and improvements made as a result of feedback received and facilitators' experience of PL delivery. The PL programmes have subsequently been packaged so that principals are able to access them online, and work through each of them individually or in groups (principals, principal and STEM leadership teams). The programmes can be delivered by principals or STEM leaders as the facilitators, to appropriate groups, or by system leads.

Each programme was designed to support principals to lead initiatives promoting STEM teaching and learning and to foster a positive STEM culture in their school. By working through the materials (PowerPoint lectures, facilitator notes, resources and references) principals can:

- enhance their understanding of organisational culture in order to more effectively lead educational change;
- enhance, build and reflect upon current STEM teaching and learning initiatives/ planning in their school; and
- share and critique their school's STEM practice with colleagues, including principals in other schools.

The PL modules are designed for principals and STEM discipline leaders in both primary or secondary schools across all educational jurisdictions, states and territories.

This chapter summarises the findings of the literature review and desktop audit before describing the structure and content of the PL programmes and constituent modules. The chapter concludes with a summary of participation in the PASL PL.

4.2 Evidence underpinning programme and module development

The PASL team thoroughly reviewed both academic literature about STEM leadership in schools from 2000, and publicly available documents describing and reporting on STEM initiatives in Australia in recent years. These reviews commenced at the beginning of the PASL project and were ongoing through its first year. The findings informed the development of the PL programmes from initial conception and contributed to their refinement as the trials continued.

4.2.1 The PASL Systematic Literature Review

The systematic literature review conducted as part of PASL found that much of the research considered a single STEM discipline, most commonly science or mathematics. Very little peer-reviewed research had examined integrated models of STEM. The methodology and findings are described in detail by Beswick, Fraser, Geiger, and Randles (under review), and a synopsis of the findings is published in the professional journal Australian Educational Leader (Likourezos, Beswick, Geiger, & Fraser, 2020).

The model of STEM capability (described in Section 3.2) was used to structure the review, the findings of which are summarised in relation to four of these dimensions, namely:

- *STEM discipline-specific and interdisciplinary knowledge, skills and practices;*
- *Contexts*;
- *Dispositions*; and
- *Tools*.

The remaining dimension, Critical Orientation, was not examined separately; but, instead evidence in relation to it was sought in the literature relating to each of the other four dimensions, consistent with the embedded nature of a critical orientation in our conceptualisation of STEM capability.

4.2.1.1 STEM discipline-specific and interdisciplinary knowledge, skills, and practices

Research related to the STEM discipline-specific and interdisciplinary knowledge, skills and practices, a dimension of STEM capability, was predominantly concerned with science and mathematics. A key issue is the difficulty experienced in recruiting science teachers, in Australia and internationally (Hung & Mui, 2009) – a difficulty exacerbated by a shortage of teachers with appropriate qualifications, in addition to ageing teaching workforces (Christie, 2006). The perceived unimportance in primary schools of science compared with mathematics and literacy (Sandholtz & Ringstaff, 2016; Smetana & Coleman, 2015) is also an issue.

The role of principals was seen in terms of:

- managing, prioritising, and building coherence across competing system demands on schools (Slavit, Nelson, & Kennedy, 2010);
- facilitating professional development including by participating in sessions alongside teachers (Lesseig, 2016; Nelson, 2010);
- ensuring adequate resourcing for STEM teachers and teaching (Carey, 2006); and
- creating the kinds of school environments and cultures in which the capacity of the school as a whole to enhance student outcomes can be developed (Newman, King, & Youngs, 2000).

Crucially, improving student achievement takes much more than a focus on improving the practice of an individual teacher's classroom practice (Wood, Lawrenz, Huffman, & Schultz, 2006). An important part of the principal's task is to articulate a positive vision for STEM that encourages teachers in implementing new approaches such as inquiry in science (Hung & Mui, 2009) and being open to change (Baylor & Ritchie, 2002).

Principals can assist teachers by building a school culture in which professional risk taking is supported (Smetana & Coleman, 2015). Just as collaboration among teachers is essential to this end, principals also benefit from being part of a community practice in which they can learn from and be supported by peers (Shen, Gerard & Bowyer, 2010).

The question of the nature and extent of the STEM knowledge that principals need to effectively lead STEM in their schools was broached by Nelson (2010), who introduced the concept of Leadership Content Knowledge (LCK) in relation to mathematics. She argued that principals' LCK (that is, their knowledge of the subject and their beliefs about how it should be taught) influences principals' decisions about hiring, resource allocation and policy implementation. Several researchers have argued that LCK can be developed by participating in PL alongside teachers (Lesseig, 2016).

4.2.1.2 Dispositions

Dispositions (that is, values, beliefs and attitudes) were rarely the major focus of the research reviewed; nevertheless, it was clear that principals can influence teaching, and hence student outcomes, by communicating the value they attach to particular subjects, as well as their understanding of them (Hung & Mui, 2009) through such things as their hiring and resource allocation decisions (Politis, Killeavy & Mitchell, 2007; Rayfield & Wilson, 2009). Principals can also communicate their valuing of subjects or practices by modelling behaviours they believe to be important, such as participating in ongoing PL and embracing new technologies, and taking an interest in teachers' work and achievements, along with those of students (Gaffney, 2012). The ability of principals to foster school climates in which teachers can take risk, learn from failure and persevere in their efforts to change or refine their teaching is crucial to the development of trust among members of school communities (Smetana, Wenner, Settlage, & McCoach, 2016), which is, in turn, critical to motivating teachers (Hwera & Taylor, 2011).

4.2.1.3 Tools

The literature relating to tools and principal leadership considered both physical and digital tools. It also emphasised the principal's key role in influencing the provision and allocation of resources, which included:

- providing appropriate staff (Dempsey, 2007; Hunter, 2017);
- investments in teacher professional learning (Carey, 2006; Dempsey, 2007; Hunter, 2017);
- the provision of collaboration and instructional time; and
- laboratory assistance in addition to the physical resourcing of laboratories.

The school timetable can also be considered a tool, whereby STEM classes can be assigned to spaces that support specialised teaching (O'Grady, 2009; Zengele & Alemayehu, 2016).

Digital technology was prominent in the small amount of literature related to this aspect of principal STEM capability. In addition to continual access to computers, teachers need ready access to IT support and PL (Carey, 2006). Burke (2005) also noted an evolution in understanding of the purpose of technology teachers who had previously been perceived more simply as 'fixers of technology'.

4.2.1.4 Contexts

The context in which principals support STEM includes curricular elements (for example, access to resources, syllabus requirements and student characteristics), and the assistance available to teachers (such as, initial teacher education, in-school mentors and professional learning) (Goos, 2006). It encompasses the school community which, in addition to teachers, students and parents, includes jurisdictional officers and political and civic leaders (Nebres, 2009). Principals need to account for the priorities of community members and assist them to understand the need for change and the roles that they can play in that change (Johnson, 2013). Principals are themselves a key part of the context in which they operate, as well as an important influence on that context (Goos, 2006).

A few studies have documented the positive impact that principals, committed to providing access to STEM activities and programmes, and generating a positive STEM culture, can have on socio-economically disadvantaged and special needs students (Avendano et al., 2019; Rhodes, Stevens, & Hemmings, 2011).

4.2.2 Gaps in the Literature

The review highlights that effective STEM leadership in schools requires high levels of managerial ability, as well as the capacity to enact STEM specific instructional leadership. Challenges include critical levels of out-of-field teaching in mathematics and science, particularly the physical sciences, that disproportionately affect schools in low socio-economic, rural, and remote communities. Although principal autonomy can allow principals to respond to their school context, principals working in schools with high levels of autonomy (such as in Charter Schools in the United States) have increased responsibility for business-related matters, without the support of centralised resources (Carpenter & Peak, 2013).

Further, the review also indicates there is much more to be learned about what LCK comprises in different subjects, potentially as part of a larger research agenda examining just what principals need to know to be STEM leaders, namely:

- what subject specific knowledge do they require;
- how this knowledge differs from that of teachers;
- how this knowledge interacts with other dimensions of STEM capability; and
- how such capability might be most effectively developed.

In addition to the gaps in research/practice identified in the review, there is a need for further research on other ways STEM agendas are impacting principals' work, their responses to these new challenges and how they can best be supported to optimise potential benefits for their students.

The PASL PL programmes sought to address and/or problematise each of these gaps identified in the literature.

4.3 Evidence from desktop review

4.3.1 STEM Initiatives – Method, Data Analysis and Results

The PASL desktop audit focussed on STEM initiatives established or funded by the Department of Education, Skills and Employment, State Departments of Education, or other institutions active in STEM education. This audit summarised information from past and/or current STEM initiatives/projects based on freely available Australian websites. Data analysis was guided by the research literature (Murphy, MacDonald, Wang & Danaia, 2019; National Academy of Engineering & National Research Council, 2014), and the PASL capability framework (Geiger, Beswick, & Fraser, under review). The coding scheme comprised the following categories: Title, Website, Institution, Funding body/partner, Level of schooling, Target group, Description, Type of the initiative, Methodology used and Content area.

A summary of the categories and associated sub-categories that emerged from the desktop audit of STEM education initiatives (n=455) to improve the STEM teaching and learning at the state or national levels is presented in Table 5. Initiatives that aligned with more than one category (that is, across Teachers and Students sub-categories) were counted in all relevant categories.

Table 5: A summary of results classified by the categories in STEM initiatives (n=455)

LEVELS IN SCHOOL	TARGET AUDIENCE	TYPE	CONTENT AREA
Early years (27) Primary (206) Secondary (324) Senior (58) Tertiary (20) General (22) Not clear (47)	Students (243) Teachers (261) Principals/school leaders (43) Parents (20) Other (27) Not clear (30)	Resources (93) Events (41) Professional learning (118) Programmes (46) Competitions (59) Others (94) Not clear (31)	Mathematics (84) Science (102) Engineering (21) Technology (80) STEM (222) Other (20) Not clear (40)

In addition to levels of schooling aligned with the Australian education system (early years, primary, secondary, or senior and tertiary education) two further categories were identified:

- general (that is, initiatives appropriate to different levels of schooling), and
- not clear (that is, where the level of schooling focus was not able to be identified).

The content areas of interventions were classified into STEM (integrating two or more subjects) and individual STEM subjects (mathematics or science).

4.3.2 Gaps in the Provision of Web Resources

Primary and secondary levels of schooling were found to be the focus of the majority of STEM initiatives, while the audience for these initiatives was most commonly students and teachers. Initiatives were developed to target both STEM (integrated) and the four individual STEM subjects (mathematics, science, digital technology, and design & technology) through the provision of resources and professional learning. The areas less well addressed in current STEM education initiatives included the tertiary and early school years, families and school principals, with Engineering being the least common focus area in STEM education initiatives. An analysis of the interventions using the PASL Capability Framework indicates that the majority of STEM interventions focussed on the first two capabilities; that is, STEM discipline specific and integrated knowledge and practice and the context of the intervention. The PASL PL programmes sought to address and/or problematise these gaps.

4.4 Professional Learning module descriptions

Each PL programme consists of six or seven modules (see Figure 4) designed such that principals can work through one, two or three programmes sequentially, or in any order. In addition, the PASL PL programmes and associated resources were designed from the beginning to ultimately be a freely available online resource, to be used by principals working alone or in groups, with or without a facilitator, and using delivery modes from fully online to in person, or in blended mode.

The materials were designed in recognition of the fact that principals and their schools will:

- be at different places in their STEM journey,
- have differing visions of STEM for their schools,
- have differing contextual constraints and affordances, and
- have different approaches to meeting their STEM PL needs.

Principals engaging with PASL PL will also differ in their experience as school leaders and the extent to which they have a background in, or familiarity with, STEM disciplines. The PASL project trialled the PL in as diverse as possible a range of contexts and with as diverse as possible a range of principals to ensure that the materials are adaptable to these differences and useful in them all.

Each programme, therefore, begins with three core modules, which are essential for principals commencing the PL and which connect STEM leadership with existing understandings that they may have about their role as school leaders. Each module within each programme consists of a set of PowerPoint slides and a corresponding set of facilitator notes to guide progress through the associated resources, which include key points, activities and hyperlinks.

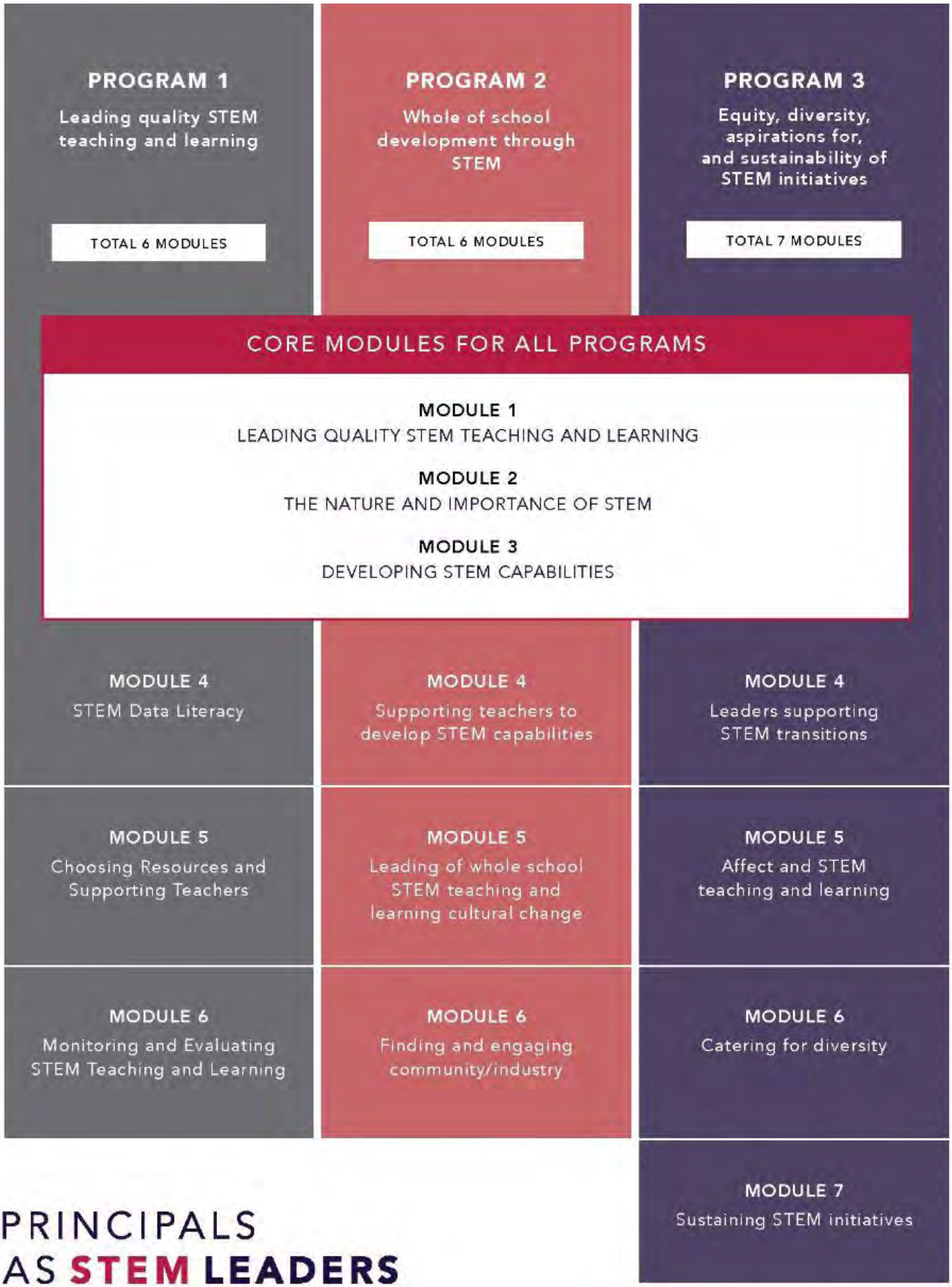


Figure 4: Structure of the PASL PL programmes and focus of modules

4.4.1 Programme 1 – Leading Quality STEM Teaching and Learning (six modules)

Organisational change research (Giles & Palmer, 2015) indicates that the principal must be an integral and active member of any innovation planned for their school. In Programme 1 (see Table 6), principals engage with the following:

- how to apply the current research literature related to the effective leadership of sustainable educational change with particular emphasis on teacher and student learning;
- understanding the importance of STEM learning (STEM literacy, STEM specialist discipline learning, STEM integration), and how it relates to the Australian Curriculum, the National STEM strategy, global advances in STEM, and where it fits with related Education initiatives;
- what effective STEM teaching looks like, and the capabilities principals and teachers need to foster student learning in STEM;
- opportunities and processes provided by the effective use of data when planning for STEM professional learning/interventions;
- the evaluation of resources for STEM teaching and learning, with reference to specific research-based tools; and
- approaches to monitoring the quality of STEM teaching/learning as an important component of teaching and learning.

Table 6: The foci of each module in Programme 1

PROGRAMME 1	
MODULE	**FOCUS**
MODULE 1: CORE LEADING QUALITY STEM TEACHING AND LEARNING	• This module supports principals' leadership of the introduction and consolidation of STEM projects in their school's curriculum. • The principles presented and promoted in this module draw from current theoretical and research literature from the fields of education, management, and business. • Principals will enhance their knowledge about both the nature of contemporary leadership and how this influences the way in which educational change can be led and supported.
MODULE 2: CORE THE NATURE AND IMPORTANCE OF STEM	• In Module 2, 'STEM' is situated within the context of Education. • Participants are introduced to the theoretical framework that underpins the whole PASL project: a model for STEM capability. • This model is based on five dimensions: STEM discipline and interdisciplinary knowledge and practices, contexts, dispositions, tools, and critical orientation. • The STEM capability model is re-visited in subsequent programmes and modules.
MODULE 3: CORE DEVELOPING STEM CAPABILITIES	• Module 3 extends the ideas presented in Module 2 by unpacking the details of the STEM Capability Sets. • Principals are guided through each of the Capability Sets developed for principals, teachers, students, and community, to inform their vision of STEM learning and teaching.
MODULE 4: STEM DATA LITERACY	• The concept of data literacy is introduced in Module 4. • This concept is explored in relation to the many ways that data literacy is key for principals' decision making in the context of their schools. • The need for a whole of school approach to data literacy is highlighted in the module and emphasis is placed on the importance of principals leading and supporting the development of teachers' data literacy, who, in turn, can promote these skills in their students. • A framework for data-based inquiry (Mandinach & Gummer, 2016) is also introduced in the module, with advice on how principals can apply it in context. • This framework is re-visited in subsequent programmes and modules.
MODULE 5: CHOOSING RESOURCES AND SUPPORTING TEACHERS	• In Module 5, the Mandinach and Gummer (2016) framework is used to engage principals in discussion about STEM educational planning. • Principals are encouraged to identify data that can or should be accessed, to inform decisions about STEM resource acquisition and the STEM capability development support needed by teachers, students and community.
MODULE 6: MONITORING AND EVALUATING STEM TEACHING AND LEARNING	• The final module for Programme 1 is based on an inquiry framework designed to assist principals to identify the questions that should be asked, and the relevant data required to effectively progress their plans for STEM education. • Advice is also provided that is relevant to key AITSL documents, as well as the goals of the Australian Curriculum, essential reading through the process of establishing the goal(s) for their planned STEM initiative.

4.4.2 Programme 2 – Whole of School Development through STEM (6 modules)

In Programme 2 (see Table 7), principals commence with the three core modules (Modules 1, 2, and 3), with additional modules aimed at extending their thinking about whole of school approaches to planning and implementing STEM interventions by:

- auditing their schools' current level of engagement with STEM, and identifying their current needs and interests on a spectrum of STEM development;
- assessing the resourcing needs of the school, including identifying strategies to support teachers (experienced, new, out-of-field) to engage in STEM education and develop their STEM capabilities;
- identifying the types of interventions and professional learning that both individuals and small teams of teachers might undertake to enhance their STEM capabilities;
- critiquing the Quality Professional Learning Framework (QPLF) as an example of a resource that can assist the development of contextually relevant plans and interventions for whole-of-school teacher engagement with STEM teaching; and
- considering the place of community expertise and industry resources in STEM planning.

Table 7: The foci of each module in Programme 2

PROGRAMME 2	
MODULE	**FOCUS**
MODULE 1: CORE	• As in Table 6
MODULE 2: CORE	• As in Table 6
MODULE 3: CORE	• As in Table 6
MODULE 4: SUPPORTING TEACHERS TO DEVELOP STEM CAPABILITIES	• Module 4 provides both theoretical and practical stimuli for principals as they seek to more effectively support the (developing) STEM capabilities of teachers in their schools. • Principals are guided through approaches to fostering teacher professional learning within the dimensions of the STEM capability model. • Quality resources that support teacher professional learning in STEM are also identified.
MODULE 5: LEADING WHOLE SCHOOL STEM TEACHING AND LEARNING CULTURAL CHANGE	• This module extends the ideas introduced in Module 1 (core) by focussing on the creation of an ongoing STEM-positive school culture to facilitate sustainable and lasting organisational change. • It focusses on the issues that principals should consider and capabilities they benefit from developing to confidently lead the successful introduction, and then consolidation, of STEM initiatives in their school. • The importance of understanding the school's culture prior to engaging in cultural change is highlighted, and principals are encouraged to engage parents and the community in plans to develop a positive STEM culture.
MODULE 6: FINDING AND ENGAGING COMMUNITY / INDUSTRY RESOURCES	• The final module in Programme 2 supports principals to identify, create and foster relationships in the community and with industry. • The importance of establishing strategic STEM partnerships is emphasised, as such partnerships assist with the promotion of effective STEM learning and the awareness of STEM career pathways throughout the school community. • Principals are encouraged to reflect on their own planning for ongoing and sustained improvement in the development of community and industry relationships for their school.

4.4.3 Programme 3 – Equity, Diversity, Aspirations for, and Sustainability of STEM Initiatives (7 modules)

In Programme 3 (see Table 8), principals commenced with the three core modules (Modules 1, 2, and 3) before completing four remaining modules aimed at extending their understanding of STEM capabilities by:

- examining key features of STEM initiatives that recognise student diversity and foster student learning;
- considering ways of gathering and analysing data in order to manage the natural transitions in education systems and their impact on STEM teaching, learning and capability development;
- reflecting on moments of transition, including students transitioning between early childhood, primary and secondary schooling;
- identifying appropriate policies and procedures for induction of teachers and principals transitioning into and out of the schools;
- gathering their own data about the potential impact of school structures and cultural norms on their teachers and students' engagement in STEM;
- investigating such things as principals, teachers and students' affect and beliefs about STEM, the influence of context and impact of student diversity, and silo-based departmental and organisational structures; and
- considering the usefulness of state-based and national support available for STEM education initiatives to their own school's contexts.

Table 8: The foci of each module in Programme 3

PROGRAMME 3	
MODULE	**FOCUS**
MODULE 1: CORE	• As in Table 6
MODULE 2: CORE	• As in Table 6
MODULE 3: CORE	• As in Table 6
MODULE 4: LEADERS SUPPORTING STEM TRANSITIONS	• In Module 4, principals examine the significance of transitions for principals, teachers, and students. • Principals engage with the issues that add to the challenges of these transitions, which can affect school culture and that need to be managed through strategic transition planning. • The module provides principals with opportunities to reflect on and plan for different STEM transition contexts and objectives pertinent to their situation.
MODULE 5: AFFECT AND STEM TEACHING AND LEARNING	• The important concept of affect and its impact upon learning and teaching in STEM educational contexts is introduced in Module 5. • Principals are encouraged to consider the impact of their own beliefs and dispositions in fostering a whole of school STEM initiative, and to recognise the ways in which their teachers' beliefs can help promote students' STEM capabilities.
MODULE 6: CATERING FOR DIVERSITY	• In Module 6, principals are supported to consider how schools can cater for diverse learners in STEM, with a focus on learners who are often marginalised in STEM education. • Principals examine the extent of diversity that should be considered in STEM education initiatives and how they are able to influence change in their schools. • The issues relating to specific groups of students that are considered diverse/ marginalised learners in STEM are highlighted, and principals consider how this diversity or potential/actual marginalisation can be identified and addressed.
MODULE 7: SUSTAINING STEM INITIATIVES	• The final module of Programme 3 draws together and builds on ideas introduced in all three PL programmes. • Principals are introduced to ways in which to consider and measure success and sustainable STEM initiatives. • In this module, principals are encouraged to work through activities with their STEM leaders and other teaching groups to optimise learning and the potential for action. • The activities enable participants to discuss and problem solve the issues that are unearthed in their own context.

4.5 Participation in PASL PL trials

PL Programme 1 sessions commenced on 10 May 2019; and concluded on 30 July, 2020, with data collection continuing until early September 2020. COVID-19 caused a pause in both PL delivery and data collection on 21 March, 2020. In agreement with DESE, some PL was rescheduled in specific permissible jurisdictions on 7 May, 2020, in response to project monitoring of weekly COVID-19 updates from each state and jurisdiction.

The project's participation target range was 108 to 210 principals to complete the PL over the course of the project. The lower range of the target was exceeded, but the upper participation target was impacted by COVID-19 restrictions and on the subsequent participant withdrawals due to the related challenge of leading schools in a time of a global pandemic.

By way of context, large clusters in the processes of consent in four regions were unable to proceed due to restrictions on approaching schools, vulnerable cohorts and on the timing of the research, within the project timeframe. These schools are not included in the data and highlight that participation rates would likely have achieved the original project participation targets prior to the impact of COVID-19 on Australian schooling.

Table 9 provides a summary of principal and STEM leader participation in the PL between 4 September, 2018 and 30 July, 2020. A total of 148 participants completed the PL, comprising 81 principals and 67 STEM leaders and teachers. A further 23 principals from around Australia participated in an initial two-day workshop held at the University of Tasmania, September 4-5, 2018. This cohort of principals provided initial input into the development of the PL modules, critical friends approach, and PL needs.

Table 9: PASL Principal PL participation

STATE	PROGRAMME 1 PRINCIPALS	PROGRAMME 2 PRINCIPALS	PROGRAMME 3 PRINCIPALS	SUBTOTAL PRINCIPALS
Total	37	23	21	81

Table 10 summarises representatives from STEM leadership teams (that is, Assistant Principals, Heads of discipline, STEM leaders and STEM system consultants) who have participated in the PL.

Table 10: PASL STEM Leader/Teacher PL participation

STATE	PROGRAMME 1 AP/TEACHERS	PROGRAMME 2 TEACHERS	PROGRAMME 3 TEACHERS	SUBTOTAL TEACHERS
Total	37	26	4	67

A total of 70 principals withdrew from the project, either prior to, or post-PL. Of this total, 50 withdrew due to the impact of COVID-19 on schooling. Of the 20 non-COVID-19 related withdrawals, the following reasons or circumstances were cited by principals (or their contacts):

- changed schools,
- commenced long service leave,
- strategic shift in systemic priorities requiring a school refocus,
- experienced serious/terminal Illness or family emergency, and
- passed away.

While after initially indicating interest, some principals did not provide a reason; rather, they remained uncontactable by the PASL team after a protracted period of time and several follow-up attempts (on average, five).

5 Survey results

5.1 Introduction

This chapter reports the findings from an analysis of principal, teacher, and student survey data.

The principal findings are reported in two ways:

- evidence of change and stability post-PL; and
- principals' STEM beliefs associated with positive leadership and school culture.

Teacher findings are reported in two parts due to the relatively larger number of mathematics and science teacher respondents which allowed additional analyses to be conducted for this group:

- teachers of mathematics and/or science, and
- teachers of design and technology, digital technology and/or integrated STEM.

Student data and findings look at the following aspects:

- belief;
- engagement in STEM domains and perceived classroom and teacher factors in STEM domains;
- STEM-related career aspirations; and
- 21st Century skills.

The chapter closes with the implications these findings have for practice.

5.2 Principals

Principals from 104 schools were invited to complete a Time 1 Survey prior to their completion of the PASL PL, and a Time 2 Survey within approximately six months of completing PASL PL. Of the 104 principals invited, 87 completed a Time 1 Survey, 34 of whom completed the Time 2 Survey.

This report includes those 34 principals who completed both Time 1 and Time 2 Surveys. These data provide a comparison of principals' perceptions about leadership and STEM before and after completion of the PL, and their interrelationships.

Table 11: Principals' Demographic Characteristics

	WHOLE SAMPLE *n* (%)	PRIMARY *n* (%)	SECONDARY *n* (%)	MIXED *n* (%)
GENDER				
Male	12 (35.3)	8 (40.0)	2 (22.2)	2 (40.0)
Female	22 (64.7)	12 (60.0)	7 (77.8)	3 (60.0)
ABORIGINAL AND/OR TORRES STRAIT ISLANDER				
ABSTI	1 (2.9)	1 (5.0)	0 (0.0)	0 (0.0)
Other	33 (97.1)	19 (95.0)	9 (100.0)	5 (100.0)
HIGHEST QUALIFICATION				
Bachelor	13 (38.2)	7 (35.0)	4 (44.4)	2 (40.0)
Master	19 (55.9)	11 (55.0)	5 (55.6)	3 (60.0)
PhD	2 (5.9)	2 (10.0)	0 (0.0)	0 (0.0)
TEACHING AREA				
Mathematics	1 (2.9)	0 (0.0)	0 (0.0)	1 (11.1)
Math. & Science	1 (2.9)	1 (5.0)	1 (11.1)	0 (0.0)
Technology	1 (2.9)	0 (0.0)	0 (0.0)	0 (0.0)
Tech. & Generalist	1 (2.9)	1 (5.0)	0 (0.0)	0 (0.0)
Generalist (that is, primary)	20 (58.8)	18 (90.0)	1 (11.1)	1 (11.1)
Other	10 (29.4)	0 (0.0)	0 (0.0)	7 (77.8)
STEM QUALIFICATIONS[7]				
Mathematics	2	1	0	1
Science	2	1	0	1
Technology	3	1	2	0
None	23	13	6	4
WORK EXPERIENCE	M (SD)	M (SD)	M (SD)	M (SD)
Time in schools (yrs.)	29.51 (6.98)	29.45 (7.87)	28.92 (6.71)	30.83 (3.81)
Time as principal (yrs.)	9.93 (7.30)	12.80 (7.02)	6.24 (5.82)	5.05 (5.82)
Time as principal in current school (yrs.)	4.36 (3.89)	5.62 (4.21)	2.81 (3.13)	2.12 (1.23)
Hours worked per week	48.83 (16.60)	47.33 (15.68)	51.25 (7.44)	51.00 (30.20)
Hours worked weekends	5.54 (4.00)	5.39 (4.63)	4.67 (1.03)	7.50 (3.79)
Hours teaching per week	2.10 (5.12)	1.89 (5.52)	0.71 (1.50)	4.80 (6.61)

[7] As participants could select multiple options for this question, a percentage is not informative. Three principals did not respond.

5.2.1 Participants

Demographic characteristics of the school principals are summarised in Table 11, of their schools in Table 12 overall, and per school level (that is, primary/secondary/mixed). Principals came from 34 schools: 20 primary, nine secondary and five mixed. Two-thirds of the principals were women, one was of Aboriginal or Torres Strait Islander background and almost two-thirds held a Master's level qualification or higher. Five principals had qualified to teach a STEM subject and seven held qualifications in STEM fields. On average, these principals had been working in schools for 30 years, had been a principal for ten years, and worked as principal at their current school for four years. On average, they were working 49 hours per working week, six hours per weekend and teaching two hours per week.

Table 12: School Demographic Characteristics

	WHOLE SAMPLE *n* (%)	PRIMARY *n* (%)	SECONDARY *n* (%)	MIXED *n* (%)
REGION				
Metropolitan	22 (64.7)	13 (65.0)	6 (66.7)	3 (60.0)
Suburban	3 (8.8)	2 (10.0)	1 (11.1)	0 (0.0)
Rural	4 (11.8)	2 (10.0)	1 (11.1)	1 (20.0)
Regional	5 (14.7)	3 (15.0)	1 (11.1)	1 (20.0)
NEW TEACHERS (LAST 12 MONTHS)				
0	3 (8.8)	2 (8.7)	1 (12.5)	0 (0.0)
1-5	24 (76.5)	15 (65.3)	5 (62.5)	4 (80.0)
6-10	3 (8.8)	1 (4.3)	2 (25.0)	0 (0.0)
16 or more	2 (5.9)	5 (21.7)	0 (0.0)	1 (20.0)
LEAVING TEACHERS (LAST 12 MONTHS)				
0	11 (33.4)	9 (45.0)	1 (14.8)	1 (20.0)
1-5	20 (60.6)	11 (55.0)	6 (70.4)	3 (60.0)
6-10	1 (3.1)	0 (0.0)	1 (14.8)	0 (0.0)
16 or more	1 (3.1)	0 (0.0)	0 (0.0)	1 (20.0)
SIZE	**M (SD)**	**M (SD)**	**M (SD)**	**M (SD)**
N students	653.27 (653.11)	443.16 (318.75)	1008.44 (942.20)	812.40 (809.08)
N teachers	51.38 (52.26)	30.20 (21.36)	77.78 (61.45)	88.60 (85.25)
N admin. staff	10.84 (12.25)	6.15 (6.47)	15.14 (13.45)	23.60 (18.61)

Two-thirds of the principals who responded to the survey were at metropolitan schools, five at regional, four at rural and three at suburban schools. The principals reported modest teacher turnover at their schools, and most reported fewer than five teachers had commenced or left during the past twelve months. On average, the schools contained 653 students, 51 teachers and eleven administrative staff.

5.2.2 Design

Principals responded to a range of self-report measures regarding themselves, their leadership practice, school culture, and beliefs about each of mathematics and science. The survey descriptions of the measures are provided in Appendix A.1. The questions addressed the following constructs:

- *Personal qualities (Time 1 only)*: openness, extraversion, conscientiousness, agreeableness, and neuroticism; priorities for future investment.
- *Leadership style*: transformational leadership, instructional leadership, support and pressure, data literacy, collecting/responding to feedback, personal involvement, need for PL.
- *School engagement*: identification with school, external engagement.
- *School culture*: collaborative teams, goal orientation, collective efficacy.
- *STEM beliefs*: intrinsic/utility/attainment values, perceived difficulty for each of mathematics and science.
- *STEM practical applications*: beliefs about tools, 21st Century skills.

5.3 Findings from the principal surveys

Detailed descriptive summaries and significance tests are provided in Appendix A.2. The *PASL Principal Report* has provided a rich depiction of the 34 participating principals' perceptions of school leadership and culture, and beliefs about STEM and STEM teaching and learning, both prior to and following the PL initiative in which they participated.

Given several of the pre-PL findings (such as these principals endorsing STEM PL as their highest valued priority) it seems likely that principals who were already keen to improve STEM teaching and learning in their schools opted to participate in PASL. This may explain some of the already very positively rated factors prior to the PL, and may have limited their potential to change after it.

Another possible explanation for the limited changes detected following the PL relates to the COVID-19 pandemic, as schools were operating remotely for a period of time and, even when teachers and students returned to school together, this may have overshadowed STEM innovation as principals' priority and limited their opportunities to concentrate on STEM improvements. Yet, a number of important messages and implications for practice can be drawn from the report findings, and these are discussed in the following sections.

5.3.1 Changes and Stability Pre- to Post-PL

5.3.1.1 Changes following the PL

Three changes were observed that were statistically significant from before until after the PL, namely:

1. Principals' increased efficacy for transformational leadership, regardless of if they were at primary, secondary or mixed schools. Transformational leadership has been identified in the literature as pivotal in effective educational innovation, including behaviours of:
    - communicating a clear and positive vision of the future;
    - treating staff as individuals, and supporting and encouraging their development;
    - fostering trust, involvement and cooperation among team members;
    - encouraging thinking about problems in new ways and questioning assumptions;
    - clearly communicating the values and beliefs they practice; and
    - instilling pride and respect in others and inspiring others by being highly competent.

2. A decrease in principals' perceived difficulty of science, regardless of their school level. Prior to the PL, the average rating for perceived difficulty of science was above the scale midpoint, but dropped below it after the PL, indicating a positive change in principals' perceptions about science. As perceived science (and mathematics) difficulty is associated with lower efficacy for instructional leadership, this change was of practical importance. There was no corresponding reduction in perceived difficulty of mathematics, however, which remained at the scale midpoint.

3. Principals' reported need for PL reduced (from an average rating just below 'moderate', to just above 'low') after they had completed the PL, suggesting principals believed the PASL PL had reduced their need for PL. This is particularly reflected in their lower need for PL about providing effective feedback, promoting equality and diversity, developing teacher collaboration and human resource management.

5.3.1.2 Lack of changes following the PL

Several factors were already highly positive prior to the PL, which may explain their lack of change following the PL. Highly rated leadership and school culture factors included efficacy for instructional leadership, principal support, school identification/belonging, collaboration, mastery climate and collective efficacy. Highly rated STEM beliefs included utility value for both mathematics and science, incremental beliefs about ability (reflecting a 'growth mindset'), beliefs about use of tools in STEM teaching and learning and 21st Century skills.

There were other factors that were less positively rated (but which did not change following the PL), including:

- the degree of principal pressure applied to staff;
- level of a principal's personal involvement;
- collection and use of feedback;
- degree of external engagement;
- performance climate (at secondary/mixed schools;
- intrinsic/attainment values for mathematics and science; and
- perceived difficulty of mathematics.

Future intervention research undertaken during principal STEM PL should target these areas.

Interestingly, few differences were observed between primary compared with secondary school principals on measured constructs, with the notable exception of a less performance-oriented focus on achievement scores and competition within primary schools, mirroring student perceptions detailed in the PASL Student Survey Report.

5.3.2 Principals' STEM Beliefs Associated with Positive Leadership and School Culture

Principal-reported beliefs about STEM with leadership style and school culture factors were connected in the analysis to determine which beliefs potentially promoted supportive school contexts, in order to identify levers for policy and practice. Patterns of association were inconsistent before the PL, but became clearer afterwards, with mostly similar correlations for mathematics/science beliefs with leadership and school culture dimensions.

Higher values for mathematics and science (intrinsic/attainment utility) related to principals' greater efficacy for instructional leadership as well as their sense of collective efficacy (for example, "Teachers in this school are able to get through to difficult students"). On the other hand, perceiving mathematics and science as difficult was associated with lower instructional leadership. Entity beliefs that one's mathematics/science abilities are fixed and cannot change also showed detrimental relationships with principals' data literacy practices and sense of collective efficacy in terms of group competence.

For mathematics, utility value additionally related to principals' use of collaborative teams, and intrinsic and attainment values to their level of external engagement with students' families, local businesses and nearby tertiary institutions. One equivocal effect was identified for principals' mathematics attainment value, which associated with pressure for teachers to achieve high student achievement scores (example items: "I assess teachers mainly by their students' performance"; "I put pressure on teachers to achieve high student grades"; "I often compare teachers' achievements to those of other schools").

This kind of principal pressure has been found to be counterproductive by undermining teachers' positive instructional goals (Shibaz & Butler, 2011). As attainment value refers to the personal belief that it is important to be good at mathematics, and mathematics is often seen as a 'high stakes' achievement domain (as reflected by the number of externally required standardised achievement test), this connection makes sense. This outcome highlights an area that future intervention research should also target, to ensure principals do not translate the personal value they attach to succeeding in mathematics into applying detrimental performance pressure to teachers.

As with all studies, the PASL study has limitations. First and foremost, due to the global health pandemic of 2020, only 34 principals completed second timepoint surveys. As only longitudinal data following same principals can examine potential changes as a result of the PL, the relatively small sample limited both the representation of principals across schools and States/Territories, in addition to the inferences that could be drawn.

5.4 Findings from the teacher surveys

Teacher survey participants and results are reported in two parts as the relatively greater number of respondents to questions for mathematics and science teachers allowed some additional analyses to be conducted for this group, namely:

1. teachers of mathematics and/or science, and
2. teachers of design and technology, digital technology and/or integrated STEM.

5.4.1 Survey Design

Teachers responded to a range of self-report measures regarding themselves, their teaching practices, school culture, and beliefs about specific STEM disciplines or integrated STEM they taught. The survey descriptions of the measures are provided in Appendix A.3. The constructs addressed are listed following:

- *Teacher attitudes towards specific STEM disciplines (or integrated STEM):* beliefs about those disciplines and the nature of intelligence.
- *Teacher instruction in specific STEM disciplines (or integrated STEM):* extent to which teachers academically challenged their students; enthusiasm for teaching; data literacy activities; and inquiry learning and teacher directed learning.
- *School culture:* principal support, external engagement.
- *Perceived efficacy:* self-efficacy in STEM subjects, STEM 21st Century skills, collective efficacy.
- *Teachers' goals:* goal orientations – mastery goals, work avoidance goals, relational goals.
- *Student engagement in mathematics and science:* curiosity.

5.4.2 Participants: Mathematics and Science

Detailed descriptive summaries and significance tests for the teacher survey concerning teachers of mathematics and science are provided in Appendix A.4. Eighty-two mathematics teachers and 77 science teachers across six States (NSW, Queensland, Victoria, South Australia, Western Australia, and Tasmania) completed surveys prior to their principals undertaking the PASL PL.

Twenty teachers taught both mathematics and science and responded to both sets of questions. This report presents survey results for these teachers of mathematics and/or science, who came from 36 schools for mathematics teachers, 37 schools for science teachers, with average two teachers per school.

Demographic characteristics of the teachers are provided in Table 13. There were more female than male participants, and few teachers identified as Aboriginal and/or Torres Strait Islander. A small number had no teaching qualification; most held a Bachelor or Diploma degree. One-third of mathematics teachers held post-secondary qualifications in mathematics; 58% of science teachers held post-secondary qualifications in science. On average, they had taught seven to eight years in their current school, and ten to eleven years in total.

Table 13: Teachers' Demographic Characteristics

	Mathematics teachers *n* (%)	Science teachers *n* (%)
GENDER		
Male	25 (30.5)	28 (36.4)
Female	57 (69.5)	49 (63.6)
ABORIGINAL AND/OR TORRES STRAIT ISLANDER		
A&STI	2 (2.4)	4 (5.2)
Prefer not to say	0 (0)	1 (1.3)
Other	80 (97.6)	72 (93.5)
HIGHEST QUALIFICATION		
Certificate	1 (1.2)	4 (5.2)
Diploma	23 (28.0)	25 (32.5)
Bachelor	49 (59.8)	45 (58.4)
Master of Teaching	7 (8.5)	4 (5.2)
Master of Education	3 (3.7)	6 (7.8)
PhD	1 (1.2)	0 (0)
None of the above	1 (1.2)	3 (3.9)
STEM QUALIFICATIONS[8]		
Mathematics	27 (32.9)	13 (16.9)
Science	15 (18.3)	45 (58.4)
Technology	4 (4.9)	7 (9.1)
Engineering	3 (3.7)	1 (1.3)
Other	1 (1.2)	1 (1.3)
None	43 (52.4)	28 (36.4)
TIME TEACHING (YEARS)	*M* (SD)	*M* (SD)
Teaching total	13.08 (10.83)	12.62 (10.21)
Time in current school	7.18 (7.54)	7.93 (7.73)

[8] As participants could select multiple options for this question, a percentage is not informative. Three principals did not respond.

5.4.3 Findings from the Teacher Survey: Mathematics and Science

As with all studies, the PASL teacher study has limitations. First and foremost, due to the global health pandemic of 2020, very few teachers in each school completed the survey. The relatively small sample limited both the representation of teachers within schools, as well as the inferences that could be drawn. It was also not possible to collect the planned follow-up surveys with teachers, following their principals' participation in the PASL programme of PL. Nevertheless, a number of important messages and implications for practice can be drawn from the teacher survey findings for mathematics and science teachers (detailed descriptive statistics are provided in Appendix A.4).

Principals' level of support or pressure was largely unrelated to either teachers' instructional practice, or to teachers' beliefs about mathematics or science. It is unclear if this result would be different, following principals' participation in the PASL PL. For science teachers only, their extent of external engagement (for example, with families, businesses or tertiary institutions) promoted adaptive instructional practices. This outcome suggests that science teachers may find it easier than mathematics teachers to connect learning to real-life applications.

For both mathematics and science teachers', confidence or self-efficacy for their own teaching abilities promoted their adaptive instructional practices (such as providing academic challenge, enthusiasm and use of data). So too did their confidence to develop students' 21st Century skills. Teachers' collective efficacy beliefs (about their colleagues' abilities) was beneficial for mathematics teachers, but not for science teachers.

Consistent with the goal theory literature (Butler, 2007, 2012), mastery goals to improve one's teaching positively related to adaptive teaching practices; however, relational goals (to develop caring relationships with students) and negative work avoidance goals, showed few relationships, although relationships that did exist were in the theorised directions. In mathematics, relational goals promoted data literacy and inquiry learning activities; there were no relationships for science. In mathematics, work avoidance goals reduced teacher enthusiasm; in science work avoidance goals were higher for teachers who found science to be more difficult.

All measured instructional practices, except teacher-directed instruction, promoted students' curiosity in mathematics. All practices promoted students' curiosity in science. Most importantly, in relation to student curiosity, was the level of academic challenge provided by teachers.

Teachers' own interest for mathematics/science was also foundational to their students' curiosity in each. Teachers who found mathematics/science more difficult dampened their students' curiosity.

5.4.4 Participants: Design & Technology, Digital Technology, and Integrated STEM

Detailed descriptive summaries and significance tests for the teacher survey concerning teachers of design & technology, digital technology and/or integrated STEM are provided in Appendix A.4. Eighteen digital technology teachers and 74 integrated STEM teachers across six States (NSW, Queensland, Tasmania, Victoria, South Australia and Western Australia) completed surveys prior to their principals undertaking the PASL PL.

Three teachers taught both design & technology, and digital technology; three teachers taught both design & technology, and integrated STEM; and one teacher taught both digital technology and integrated STEM. Where teachers taught two of the three subjects, they responded to both sets of questions. This report presents survey results for 106 teachers of design & technology and/or digital technology and/or integrated STEM, who came from 13 schools for design & technology, 14 schools for digital technology, 38 schools for integrated STEM, with an average of two teachers per school.

Demographic characteristics of the teachers are provided in Table 14. There were more female than male participants, and few teachers identified as Aboriginal and/or Torres Strait Islander. Most held a bachelor's degree or diploma certificate; 52% of the design & technology teachers held post-secondary qualifications in technology; 22% of the digital technology teachers held post-secondary qualifications in technology; and 60% of the

integrated STEM teachers held post-secondary qualifications in mathematics and/or science and/or technology and/or engineering. On average, they had taught six to seven years in their current school, and eleven to 15 years in total.

Table 14: Teachers' Demographic Characteristics

	DESIGN & TECHNOLOGY TEACHERS *n* (%)	DIGITAL TECHNOLOGY TEACHERS *n* (%)	INTEGRATED STEM TEACHERS *n* (%)
GENDER			
Male	5 (23.8)	9 (50.0)	28 (37.8)
Female	16 (76.2)	9 (50.0)	45 (60.8)
Prefer not to say	0 (0)	0 (0)	1 (1.4)
ABORIGINAL AND/OR TORRES STRAIT ISLANDER			
A&TSI	0 (0)	0 (0)	1 (1.4)
Prefer not to say	0 (0)	1 (5.6)	2 (2.7)
Other	19 (97.6)	14 ( )	57 (77.0)
HIGHEST QUALIFICATION			
Certificate	0 (0)	0 (0)	1 (1.4)
Diploma	5 (23.8)	2 (11.1)	14 (18.9)
Bachelor	12 (57.1)	8 (44.4)	40 (54.1)
Master of Teaching	2 (9.5)	2 (11.1)	3 (4.1)
Master of Education	0 (0)	4 (22.2)	4 (5.4)
PhD	0 (0)	0 (0)	1 (1.4)
None of the above	0 (0)	0 (0)	1 (1.4)
STEM QUALIFICATIONS[9]			
Mathematics	0 (0)	2 (11.1)	7 (9.5)
Science	4 (19.0)	4 (22.2)	16 (21.6)
Technology	11 (52.4)	4 (22.2)	16 (21.6)
Engineering	1 (4.8)	1 (5.6)	6 (8.1)
Other	1 (4.8)	0 (0)	3 (4.1)
None	8 (38.1)	9 (50.0)	44 (59.5)
TIME TEACHING (YEARS)	*M* (SD)	*M* (SD)	*M* (SD)
Teaching in total	15.90 (9.42)	11.88 (8.57)	13.11 (10.58)
Teaching in current school	6.31 (5.82)	7.47 (8.54)	7.33 (9.08)

[9] As participants could select multiple options for this question, a percentage is not informative. Three principals did not respond.

5.4.5 Findings from the Teacher Survey: Design & Technology, Digital Technology, and Integrated STEM

A number of important messages and implications for practice can be drawn from the report findings for design & technology, digital technology and integrated STEM teachers (detailed descriptive statistics are provided in Appendix A.4).

For mathematics and science teachers, the principals' level of support of pressure was largely unrelated to instructional practices or beliefs for the three groups of teachers. External engagement was positively related to data literacy and inquiry learning for integrated STEM teachers, but largely unrelated to practice or beliefs for design & technology and digital technology teachers.

Teachers' self-efficacy (confidence) was positively associated with adaptive teaching practices (that is, providing academic challenge, enthusiasm, data literacy and inquiry learning for integrated STEM teachers) but largely unrelated for the other groups. There was a strong association between self-efficacy and teacher-directed learning for design & technology teachers. For these teachers, self-efficacy was also strongly negatively associated with their perception that the subject was difficult. This relationship applied to a lesser extent to integrated STEM teachers but there was no connection for digital technology teachers. The self-efficacy of integrated STEM teachers was also associated with positive beliefs about the intrinsic value and utility of STEM. Collective efficacy beliefs were negatively associated with teacher-directed learning for digital technology teachers and unrelated to practice for other teachers. For integrated STEM teachers only, collective efficacy was negatively associated with beliefs that the subject was difficult.

Mastery goals to improve one's teaching were positively related to teacher enthusiasm for design & technology and integrated STEM teachers, and also with the provision of academic challenge for integrated STEM teachers. Mastery goals were also associated with positive beliefs about the intrinsic value and utility of STEM for integrated STEM teachers.

For design & technology teachers, there were no significant associations between instructional practices or beliefs about the value, utility, difficulty of the subject, or students' ability, and promoting students' curiosity. For digital technology teachers providing academic challenge and belief in the difficulty of the subject were associated with promoting students' curiosity. In the case of integrated STEM teachers providing academic challenge, teacher enthusiasm and beliefs that the subject was difficult were negatively related to student curiosity; whereas beliefs that the subject was valuable and useful were positively associated with student curiosity. Many of the differences observed between the three groups of teachers could be explained by differences in STEM background and presumably knowledge and confidence as a result; integrated STEM teachers were much less likely than others to have STEM qualifications.

5.5 Findings from the student surveys

Students from twelve participating schools (those sampled pre-COVID-19) were invited to complete anonymous surveys prior to their principal undertaking PASL PL.

These data provide a background snapshot of students' perceptions about STEM (science, technology, and mathematics) as it was being taught in each participating school. Data collection was conducted with ethics approval from the University of Tasmania[10], and approvals from Australian State/Territory governing ethics boards[11]. Independent schools were approached individually with notice given to their relevant State/Territory association.

5.5.1 Participants

The total number of student participants *N* = 1,001 came from six primary (*n* = 269), five secondary (*n* = 364) and one combined primary and secondary (*n* = 368) schools. The distribution of student survey respondents across grade levels is depicted in Table 15 (note that Y4, Y5 and so on, refer to year level).

Table 15: Student Survey Participants by States, Schools and Grade Levels

	Y4	Y5	Y6	Y7	Y8	Y9	Y10	[a]Y11
TOTAL	79	243	85	284	61	194	36	19

Low numbers of upper-secondary participants necessitated excluding them from main analyses. Demographic characteristics of the student sample are summarised in Table 16 overall, as well as broken down by age-group.

English was overwhelmingly the dominant language spoken at home, and Australia the main country of birth. Greater cultural diversity occurred among parents, about half of whom were born in Australia. There were small numbers of Aboriginal or Torres Strait Islander students across the sample as a whole (n = 27).

[10] Ethics Application Approval Number H0017470

[11] **ACT**: Education and Training Directorate. **NSW**: Department of Education and Families; Catholic Education Offices - Wagga Wagga, Wollongong, Armidale, Bathurst, Broken Bay, Maitland-Newcastle, Parramatta. **QLD.**: Queensland Department of Education; Catholic Education Offices – Brisbane, Rockhampton, Cairns, Townsville. **Vic.**: Department of Education and Training Victoria; Catholic Education Offices - Melbourne (CEOM), Sale, Ballarat, Sandhurst. **WA**: Department of Education; Catholic Education Western Australia. **SA**: Department for Education and Child Development (DECD); SA Catholic Education (Adelaide & Pt Pirie). **TAS**: Tasmanian Department of Education; Tasmania Catholic Education. **NT**: Department of Education.

5.5.2 Student Demographics

Table 16: Main Study Sample: Years 4 to 10

	PRIMARY Y4-6 *n* (%)	LOWER SECONDARY Y7-8 *n* (%)	MID SECONDARY Y9-10 *n* (%)
GENDER			
Male	258 (63.2%)	259 (76.2%)	190 (84.4%)
Female	142 (34.8%)	76 (22.4%)	30 (13.3%)
Prefer not to say	5 (2.0%)	5 (1.4%)	5 (2.3%)
ABORIGINAL AND/OR TORRES STRAIT ISLANDER			
A&TSI	11 (2.7%)	10 (2.9%)	6 (2.6%)
Other	385 (94.6%)	325 (94.8%)	211 (91.7%)
Prefer not to say	7 (1.7%)	8 (2.3%)	13 (5.7%)
HOME LANGUAGE			
English	336 (83.7%)	275 (80.2%)	187 (81.3%)
Other	67 (16.3%)	68 (19.8%)	43 (18.7%)
COUNTRY OF BIRTH			
Australia	328 (80.6%)	267 (77.4%)	165 (72.1%)
Other	75 (18.4%)	76 (22.6%)	64 (27.9%)
PARENT 1 BORN			
Australia	226 (55.5%)	198 (57.5%)	143 (62.8%)
Other	176 (44.5%)	146 (42.5%)	85 (37.2%)
PARENT 2 BORN			
Australia	196 (49.9%)	161 (47.9%)	121 (52.6%)
Other	204 (50.1%)	175 (52.1%)	103 (47.4%)

5.5.3 Design

Students responded to a range of self-report measures regarding STEM, specifically in relation to mathematics, science, technology (primary)/design & technology, digital technologies (secondary) and integrated STEM (secondary). Primary students completed a subset of questions to reduce the length of the survey for younger students.

STEM-specific questions were allocated to students dependent on their grade levels as follows:

- *Years 4 & 5*: these younger students were randomly allocated questions on only one of mathematics, science or technology.
- *Year 6*: Year 6 students were asked parallel questions in relation to each of mathematics and science.

For secondary students, any students studying integrated STEM were asked those questions, additional to either mathematics or science (randomly allocated):

- students studying only one STEM domain were asked questions only in relation to this domain;
- students studying two STEM domains were asked parallel questions for both domains; and
- students studying three or more STEM domains were randomly allocated two domains.

Unfortunately, 300 secondary students who were studying three STEM domains (mathematics, science, design & technology) did not respond to STEM-specific sections. Of these 300, participants were from both NSW and Queensland, as follows:

- NSW – 264 (226 Years 7-8 students, 35 from Years 9-10, 3 from Year 11); and
- Queensland – 36 (35 Years 7-8 students, 1 from Years 9-10).

To enable access for such students to STEM-specific sections would have made the survey prohibitively long.

The STEM-specific questions tapped several key constructs (descriptions of which are provided in Appendix A.5):

- *Perceived socialiser beliefs*: sex-typing, perceived peer value (mathematics / science only).
- *theory of intelligence*: entity (fixed) versus incremental (growth) beliefs (mathematics / science only).
- *Motivations*: perceived talent, values, costs, and achievement goals.
- *Learning environments*: mastery and performance climate, teacher enthusiasm, academic challenge, curiosity.
- *Classroom practice*: inquiry learning, teacher-directed learning, teacher support, data literacy, use of tools.
- *Student-perceived teacher beliefs*: expectation, difficulty, value, relationship.

Secondary students were additionally asked questions tapping into their STEM-related career aspirations and 21st Century skills.

School wellbeing[12] was assessed in only one state; hence, results are not included in this report.

[12] School wellbeing measures were only permitted in the NSW schools by governing ethics boards.

5.5.4 Findings from the Student Surveys

Detailed descriptive statistics for students in each grade band and for each STEM subject and integrated STEM, along with the results of correlations analyses are provided in Appendix A.6. As with all studies, the PASL student study has limitations. First and foremost, due to the global health pandemic of 2020, it became impossible to collect planned second timepoint student survey data from any students; it also was not possible to collect even first student survey data from students in schools whose principals joined the PASL study from March 2020. This limited both the representation of students across schools and States/Territories, as well as the causal inferences that could be drawn from single timepoint correlational data.

As data are cross-sectional, developmental inferences (such as declines in STEM engagement or increases in negative cost dimensions) need to be interpreted with care. Only longitudinal data following the same students over a period of years can confidently conclude about developmental changes. It is possible that differences between younger and older students in the data may be confounded by individual differences between those students, rather than the developmental progression from primary through secondary school; however, the tendencies the team identified do reflect those from true longitudinal studies among Australian students (Watt, 2004).

Another limitation arose from the need to not over-burden students with survey questions, and to limit the time it took for them to complete the survey to less than 30 minutes. This meant that students could not be asked about all domains of STEM they may have studied. The team limited the STEM-focused questions for students in Grades 5 and 6 to one STEM domain, and for students in Grades 6 and above to two studied STEM domains. Even within same grade-levels, as students responded in relation to (maximum of two) studied STEM domains, there is student self-selection into particular domains of study, such that differences in patterns (such as technology versus mathematics and science) can be due to differences in characteristics of students choosing to study each, rather than to differences inherent to each STEM domain itself. In addition, and unfortunately, only NSW students were permitted to be asked the general school wellbeing questions due to other States' governing ethics boards, despite the approval of the respective, formal university Ethics Committees.

Nevertheless, the PASL student data provide a rich depiction of 1,001 students' perceptions of STEM and STEM teaching and learning across primary, lower- and mid-secondary schools from twelve schools spanning three states. These are summarised in the following sections, followed by an outline of implications of the findings for practice.

5.5.4.1 Theory of intelligence and perceived socialiser beliefs in mathematics and science

The team asked all students questions tapping into theory of intelligence and socialiser beliefs in each of mathematics and science. Students tended to hold an incremental, rather than a fixed or entity view about their abilities in each of mathematics and science, believing they could grow and improve. However, it is concerning in 2019/2020 that, on average, students perceived boys to be better at both mathematics and science than girls. This was not dependent on grade-level, with similar mean ratings for primary, lower- and mid-secondary school students. Primary school students thought their peers valued each of mathematics and science more so than secondary school students. Students also thought their peers were more interested in science than mathematics.

5.5.4.2 Engagement in STEM domains and perceived STEM classroom and teacher factors

There was a tendency for dimensions of student engagement to decrease from primary to mid-secondary school in mathematics and science. For all examined STEM domains, there was a reverse trend for negative cost factors to increase for primary versus secondary students. That is, older students were more likely than younger students to believe that studying STEM subjects was difficult, not worth the effort and could cost friendships.

Concordantly, classroom climates tended to be perceived more positively for younger than older students,

especially in their mastery focus on learning and understanding, rather than performance focus on achievement scores and competition. An emphasis on, or encouragement for, students to think at a higher level (cognitive press), in terms of the construction of learning environments that promoted challenge and curiosity, was quite low-rated overall.

Classroom practices of inquiry learning, teacher-directed learning, teacher support, and use of materials/tools/representational tools were generally rated as occurring between 'some lessons' and 'many lessons'. Students perceived their teachers to hold generally positive expectations for their success in the STEM domains about which they were asked. At the same time, teachers believed that students found their STEM subjects moderately difficult, and to value the particular STEM domain. Students experienced moderate to high relationship quality with their STEM teachers; more so in primary school.

5.5.4.3 Classroom and teacher factors promoting students' engagement in STEM domains

The team connected student-perceived classroom and teacher factors per STEM domain with dimensions of student engagement in each, to determine which engagement components appeared most malleable to which environment factors, in order to identify levers for policy and practice.

The most malleable appeared to be students' motivations (perceived talent, intrinsic, attainment and instrumental values), effort exertion and achievement goals in relation to each of mathematics, science and integrated STEM. Interestingly, for technology subjects, there were additional associations with students' negative cost factors (such as perceived difficulty, effort and psychological costs).

Most influential positive environment dimensions appeared to be a mastery classroom climate focused on learning and understanding, teacher enthusiasm, teacher-directed learning, teacher support, teachers conveying positive expectations for student success and value of the particular STEM subject and relationship quality. It is therefore of concern that certain of these dimensions were lower among older versus younger students' perceived classroom environments, especially mastery climate, perceived teacher expectations and relationship quality.

Equivocal effects were identified particularly for two environment factors.

1. While a performance classroom climate focused on achievement results and competition showed several positive – albeit weaker than for mastery classroom climate – relationships with students' positive motivations, it also showed relationships with harmful cost factors and students' performance goal adoption. It is of concern then that performance classroom climates became more pronounced among older versus younger students.

2. Similar equivocal effects occurred for inquiry learning, resonating with the mixed effects for science learning found in the OECD Programme for International Student Assessment (PISA) 2015 (Mostafa, 2018) where (unlike teacher-directed instruction) inquiry-based activities proved beneficial only under certain conditions relating to well-managed classrooms, despite positive associations with students' attitudes towards science. In fact, the PISA data showed that students in disorderly science classrooms performed worse when exposed to inquiry activities, which appear to require well-managed learning environments for productive learning to occur. Measures of classroom structure may therefore be important to include in future studies examining effects of inquiry-based classrooms.

The cognitive aspects of classrooms, which promoted academic challenge and curiosity, appeared beneficial for students' positive motivations and effort exertion but, unfortunately, occurred with low frequency in classes overall.

5.5.4.4 STEM related career aspirations and 21st century skills

Looking ahead in time to their aspired careers, secondary school students indicated low to moderate interest to pursue careers in different domains of STEM, among which technology-related careers were rated slightly higher.

These students felt reasonably well-equipped with STEM-related skills for 21st Century skills and ways of working including collaboration, communication, being a responsible citizen, problem solving, innovation and creativity.

5.5.5 Implications for Practice

Clearly beneficial to students' positive engagement and efforts were mastery classroom climate, teacher enthusiasm, teacher-directed learning (that is, facilitating student discussion, discussing student questions, providing explanations and demonstrating ideas) teacher support, teachers conveying positive expectations for student success and value of the particular STEM subject, and relationship quality. These levers can be deliberately targeted in teacher professional learning and more generally promoted within the school culture to improve the quality and extent of students' engagement in STEM learning domains.

Particularly important to address is the apparent decline in mastery climate, positive teacher expectations and relationship quality through secondary school. Promotion of academic challenge and curiosity is another important lever for improvements, which occurred with low frequency in classes overall, regardless of grade-level. Performance-focused classrooms, which emphasise achievement and competition, need to be considered with care, given their sometimes positive (but frequently harmful) effects on dimensions of students' STEM engagement. Where associations were positive, they were however less strong than for mastery-focused classrooms, which also did not show harmful associations and would be more beneficial learning environments for teachers to create.

Inquiry learning practices (for example, students carrying out investigations and drawing conclusions) also need to be implemented carefully, and are clearly not a panacea to promote students' engagement and learning in STEM domains. The use of tools or representational tools was also not a solution, as this showed few and weak benefits (although this could be due, in part, to the quality of those measures). Teacher-directed learning showed more consistent benefits than inquiry-learning, pointing to the fact that inquiry-learning practices require careful design and implementation in order to be effective.

6 Enhancing leadership capability: principal leadership capabilities as a result of the PL participation

6.1 Introduction

In this chapter, the report findings from an analysis of principal and teacher interview data are discussed, in two ways:

1. against the dimensions of the principals' STEM Leadership Capability Sets; and
2. principals' perspectives on how key aspects of PASL PL programmes influenced their understanding of STEM education and its implementation.

6.2 Nature of contact with principals

6.2.1 Recruitment

Principals were recruited to PASL in several ways:

- expressions of Interest were sent out by system-level coordinators;
- a number of this group of principals attended an introductory session at the University of Tasmania, on the Launceston campus;
- other schools were later identified by systems as potential participants; and
- further principals were recruited though pre-existing contacts within the research team.

6.2.2 Principal and Teacher Interviews

6.2.2.1 Interview schedule

Principal and teacher interviews were scheduled to occur at four timepoints over a three-term period. The interviews occurred at the start and end of the first term, end of the second term, and then with a final follow-up six months later.

The interviews were conducted at times that suited principals and teachers. While some principals chose to release teachers, others asked for interviews to occur outside class time. Initial interviews were conducted face-to-face. Depending on the school, after the first interview, some follow-up interviews were conducted via telephone. Initial principal interviews took approximately an hour to complete, then approximately 30 minutes thereafter. Initial teacher interviews took approximately 45 minutes to complete, then approximately 30 minutes thereafter.

In response to the COVID-19 pandemic, all interviews were conducted via telephone, Zoom or Microsoft Teams software platforms. The research design was also modified, and the interview schedule was reduced so that contact occurred only with the principal and one lead teacher. Only two interviews were conducted with each participant. These changes primarily affected the principals participating in Programmes 2 and 3.

6.2.2.2 *Interview content*

The principal and teacher interviews included questions on:

- the school and STEM;
- classroom practice (pedagogy, assessment, curriculum, equity, school environment, reporting, systemic supports and a classroom scenario);
- leadership; and
- following the commencement of COVID-19, two questions were added that explored the impacts of the pandemic on STEM programmes.

6.2.2.3 *Principal and teacher reaction to contact*

Throughout the interviews, principals and teachers expressed their appreciation at being afforded the time to reflect on their leadership and on how STEM was being approached in their various schools. Although often time-poor, principals and teachers appeared happy to have the opportunity to discuss STEM with the research team; moreover, conversations with principals and teachers revealed high levels of enthusiasm for implementing STEM within their schools and their eagerness to learn, receive guidance and explore current resources that would help them to most effectively plan for STEM teaching and learning. For example, one interviewee noted:

> *So, with the PL sessions probably the greatest, well several things: Time to reflect, colleagues to reflect with and off of and bounce and - for me is probably the greatest gift of it. To have that time to step away. To have deep conversations with a strong basis of theory around leadership and change. But also that chance to sort of reflect back and actually say well "Ok so this is what we're doing, this is why we think it's right" (Prog1A_P2_Int2).*

6.2.3 Professional Learning Sessions

For Programme 1, principals were organised into two clusters, whereby each cluster attended two PL sessions over a two-term period in a crossover research design (as described in Chapter 3). The PL sessions for each cluster were held at the beginning and end of a particular term. These were face-to-face sessions and were held either at a nominated school or at a university research centre.

In Programme 1, only principals attended the PL sessions (although invitations to participate included the possibility of bringing additional staff). In Programmes 2 and 3, principals took up this option more frequently. The feedback from schools reflected this was beneficial in effectively disseminating the professional learning to key staff.

Following the beginning of the COVID-19 pandemic, the PL sessions moved to online forums (either Zoom or Microsoft Teams). The PASL Team found that Microsoft Teams was the most effective platform to use for the PL Sessions, as the Teams software worked more effectively with Department of Education school firewalls. Principal feedback on the move to online learning was mixed: some interviewees appreciated the convenience and flexibility, while others felt that some of the discussion and collegiality was lost in an 'online environment'.

6.3 Results from interviews

A total of 457 interviews were conducted over the course of the project, comprising:

- 196 principal interviews, and
- 261 teacher interviews.

Principal and teacher interviews were analysed according to the dimensions of the STEM Capability Set for principals, and then for evidence for change attributable to principals' participation in PASL PL. In the following sections the results, in relation to the principal STEM Capability Set first for principals and then teachers, before considering evidence for PASL PL influenced change, are presented.

6.3.1 Findings Related to Principals' STEM Capability

In the following sections are the findings from an analysis of principal and teacher interview data related to leadership and STEM education. These findings are reported according to the dimensions of the Principals' STEM Leadership Capability Sets and take the form of summary commentary, supported by representative quotes. These quotes have been drawn from transcribed principal, middle leader and teacher interviews, coded against the dimensions of the STEM Leadership Capability Set relevant to the interviewee.

6.3.1.1 STEM discipline and integrated knowledge and practices

Many principals felt the PL provided a clarification and deeper understanding of their role as a leader in STEM Education. Their observations are detailed below.

6.3.1.1.1 Clarification of their role as a leader in STEM Education

In most cases this meant a shift from a need to have a personal technical knowledge of the STEM discipline toward a view of themselves as a facilitator of:

- the development of a vision of STEM education in their schools;
- the enabling of other staff members' leadership;
- information sharing in relation effective STEM learning environments; and
- an ongoing agenda and discussion around STEM education.

6.3.1.1.2 Principal discipline-specific STEM knowledge differed

There were several principals who expressed relief at "not needing to know everything" and that their role was to support others with more technical expertise. At the same time, there was a noted trend across the data that there were more effective outcomes when principals remained involved in strategic decision-making, rather than delegating the responsibility in totality to another member of staff.

The realisation, through PASL PL, that their role was to provide leadership in STEM and not to be a STEM 'expert' prompted some principals to comment that they now felt more confident in the role of STEM leader. At the same time, one principal felt somewhat overwhelmed by what was needed for leadership in STEM after attending PASL PL, especially when reflecting on whether they had made a difference. Some principals saw STEM as being woven through other subject areas; others saw it as a stand-alone subject. Many principals had a strong initial focus on digital technologies (particularly coding), but changed their viewpoint through their participation in PASL PL. Many principals were heavily focused on inquiry-based and project-based learning for STEM.

I don't have to be an expert is really important and that I feel a lot more, you know, not "I don't know everything", but a lot more confident in being able to have a conversation in that space than I did prior to going through those workshops (Prog1A_P4_Int3).

In general, principals reported they had developed a deeper knowledge of what STEM could be in their schools after engagement with PASL PL activities.

6.3.1.1.3 Principals' understanding of STEM education and STEM leadership

Principals developed an overarching conceptual understanding of STEM education and STEM leadership, and in particular, and this was attributed to discussion during PL of the Principals' STEM Leadership Capability Sets; namely:

- different forms of leadership;
- different ways STEM could be implemented;
- using data to inform leadership and STEM teaching and learning; and
- the use of resources and tools for STEM, particularly a re-evaluation of the role of digital technologies.

I think I've got a better understanding of STEM myself a little bit, so I think probably the conversation with other colleagues has been really helpful in terms of what's working in other schools and just hearing what other people are doing. I suppose the things that I've probably taken out the most from it was some of the frameworks from the first one (Prog1B_P8_Int3).

6.3.1.1.4 A deeper engagement with the challenges associated with interdisciplinary approaches through cross-curricular initiatives.

Principals' understanding of what is meant by STEM education and the vision of how it could be enacted in their schools varied between schools. Integrated STEM was more readily embraced and implemented by primary school teachers than secondary school teachers. Principals felt that interdisciplinary approaches were particularly challenging within secondary schools where departments often worked in 'silos'.

At the same time, most principals indicated they had developed a deeper understanding of the challenges associated with interdisciplinary approaches through their participation in cross-curricular initiatives. This new understanding of issues included factors such as:

- the degree of integration;
- alignment with the Australian curriculum;
- whether to adopt STEM or STEAM approaches, or not;
- a crowded curriculum;
- siloed assessments in senior year levels that had flow down affects throughout high schools;
- teacher resistance to change, partly because of time constraints, and because some high school teachers were concerned about the integrity of the units they liked to teach, if cross-curricular teaching was implemented; and
- building teacher capacity in STEM.

We have a STEM subject at school here in the junior secondary so that makes it easy to integrate a bit and in primary school it's a little easier to integrate. Secondary teachers are very focused on their subjects in their silos and the Australian curriculum is too. Unless we have school-specific subjects like STEM, the integration won't happen, but I guess my own opinion is that it needs to happen. (Prog1B_P6_Int3).

6.3.1.1.5 *An awareness of the need to develop an understanding of opportunities for students in potential STEM careers.*

While principals had an awareness of the importance of STEM, this was primarily informed by school system policy initiatives or statements of strategic direction. Few principals were able to describe the nature of professions related to STEM or the connection between how students engaged with STEM at school, in terms of a choice of career.

6.3.1.1.6 *A focus on staff capability rather than the acquisition of resources alone.*

Some principals realigned their focus by developing plans for enhancing teachers' STEM knowledge and instructional capability with available resources; however, some principals also had to actively encourage teachers to engage with STEM, particularly when it came to upskilling in digital technologies where they, at times, experienced resistance. The importance of relevant professional learning opportunities for teachers was not a universal view as some principals appeared satisfied that the use of STEM related resources in classrooms or the development of school STEM facilities was enough to meet the demands of STEM education.

> *So as part of the four-year plan, STEM is definitely a focus for us as a school. So we've got precision, differentiation and collaboration, our three pillars, and under precision one of them is the STEM space and ensuring that we have a clear plan of action for the next four years. So the aim is 1) to support staff, 2) to ensure we have the specialisation of skills and making sure we cover the curriculum properly (Prog1A_P4_P4B_Int3).*

Many principals were active in promoting knowledge about STEM education with their staff. Their goal was to improve attitudes towards, and engagement with, STEM.

> *I now know that unless I start going to all of these things that I promote to the teachers that my impact is going to be minimal. So it doesn't matter how much money I throw at them and opportunities and give them beautiful resources and things like that. What means the most to teachers is that you actually take a personal interest in them (Prog1A_P3_Int2).*

6.3.1.2 *Contexts*

Principals commented on how they had become more aware of the importance of contexts in shaping a vision for STEM education within their schools. These contexts included the nature of the school community and other partnerships they wished to establish. They identified communication as key to establishing a STEM vision within a school community. They were also aware that resistance from some elements of their community had the potential to derail their efforts if they could not get their key messages across. The key points that principals raised are detailed in the following sections.

6.3.1.2.1 *The need to develop a vision of STEM education within their schools – a shared vision that all staff could articulate.*

The development of a STEM vision was particularly important, as state and national curriculum documents did not provide (or are silent about) the nature of STEM and how it might be implemented. This vision needed to be tailored to the specific features of their schools. Some principals also commented on a need to refine their vision of STEM, over time, to align with what it means in their school community.

> *So we're really going back to what's the vision, what's our shared understanding, and then looking at that framework [STEM Capability Sets] and seeing if it's something we can use (Prog1B_P8_Int3).*

A number of principals also commented that a vision must have a specific focus; for example, the sustainability practices within the school environment. Such initiatives were seen to promote collaboration between students and teachers towards a specific goal – providing opportunities for enhancing students' understanding of how to go about addressing real-world problems. These initiatives were very well received by students.

6.3.1.2.2 Accommodating local needs

Most principals were aware of the challenges associated with accommodating local needs, while also aligning initiatives with system wide priorities. Some principals noted the importance of co-ordinating school system and parents' expectations about directions in curriculum. These links were seen as essential in order to accommodate local needs, while also aligning initiatives with system-wide priorities. These considerations were also important in school strategic planning to complement to the direction of teaching and learning, teacher professional learning, funding opportunities and infrastructure development.

> *Our students have been overwhelmingly engaged. Children, parents have to come back to me and said "When I've asked my son what has he enjoyed most this year about learning at school, he has said I have enjoyed the fact that we are all learning STEM and we are all focusing on sustainability." And to me that has been the greatest impact (Prog1B_P4_Int2a).*

6.3.1.2.3 Meeting the demands of state and national curriculum documents while looking to take advantage of opportunities for students to work in an interdisciplinary or cross disciplinary way

In some schools, principals had to consider the additional complexity associated with STEAM education, as this was sometimes a systemic direction they were required to address. While some accommodated this requirement, others negotiated to maintain a focus on STEM. In one instance, the principal believed the school had already developed a thriving Arts programme and a focus on STEM alone was needed to promote student engagement and participation. They were confident about taking this position as they had identified key members of staff who were strong in the different disciplines within STEM and, in particular, with technology. This had impact on resources allocation, which was justified by referring to the expectations of the broader school community that had been key in the development of their school's four-year plan.

6.3.1.2.4 Establishing partnerships – locally, systemically, and internationally

One of the roles of principals within STEM education is to establish partnerships, locally, systemically, and in some cases, internationally. Examples of such partnerships, identified within the duration of the PASL project, included:

- an international partnership with Papua New Guinean schools related to agriculture, which had a focus on ancient sciences, indigenous culture and connection to the land – specific climates and micro-climates; and
- establishing networks and connections with other schools that promote STEM.

6.3.1.2.5 Planning for sustainable change

Encouragingly, most principals had a focus on planning and collaboration with STEM leaders to ensure STEM changes (units being designed, both integrated and otherwise, resource allocation, for example) they implemented were sustainable within their school context. A number of principals commented that an underestimated aspect of STEM planning was attention to the built environment. This could take the form of a room, or in some cases, a building devoted to STEM.

What I want to see in the future is a continuation of the connection to STEM and for the teachers to understand that for every single KLA … they can't compartmentalise the knowledge that they have. Every single part of it has a meaning to what's happening for the students' learning and a deep understanding of that subject. And I think the transdisciplinary model allows kids to think outside just the focus area to actually look at what that means in the big picture (Prog1A_P1_ Int3).

6.3.1.2.6 Developing flexible approaches to change

Principals expressed frustration there was no 'one size fits all' approach to STEM or that there wasn't clearer guidance, but they appreciated that the unique characteristics of their schools would have an impact. Principals found the tools on cultural change and growth mindsets from the modules beneficial. One principal suggested that a way forward in relation to managing staff concerns about potential failure was the adoption of "growth mind sets" as an idea for addressing age appropriate pedagogy.

How do you construct culture? Therefore, I would say the strongest piece of work for me coming out of that, those workshops, has been around that consideration of culture and what is it you're trying to build? And how are you trying to move forward? (Prog1A_P2_Int2).

6.3.1.2.6.1 Engaging the school community with STEM

Principals also saw the celebration of the success of school STEM initiatives as a way of supporting a positive STEM culture. Approaches to community expectations about school STEM initiatives and building a positive STEM culture included an annual science fair. This fair is an example of how schools can implement a focus on engaging parents and carers with their child's STEM learning.

Things like we have an annual science fair. So, they really help. Parents love that engagement of community in events. So, we have identified the success of that and how perhaps even next year we can build that a bit more and even look at other areas of STEM and try and do something similar (Prog1A_P4_Int2).

6.3.1.3 Dispositions

To develop a positive STEM culture in their schools, principals must first believe that all students and teachers can develop/enhance their STEM capabilities. They must also be open to innovative STEM programmes that require new pedagogical practices and have the confidence and commitment that these can be initiated, managed and brought to fruition. Principals must also be willing to be personally and actively involved in establishing and sustaining new initiatives. This requires flexible and adaptable leadership practices so that all participants feel supported and encouraged in their engagement with the STEM project regardless of differences in levels of knowledge, skill and confidence. The principals' reflections on these issues are detailed following.

6.3.1.3.1 Equity and STEM capability development

Principals' views about the need for all students to develop their STEM capability was overwhelmingly positive. They believed issues related to equity (for example, socio-economic and gender) challenges that could be addressed. In particular, they saw young women developing an increasing confidence about themselves as mathematicians. Schools had also found ways to manage differences related to accessing digital technologies through, for example, low-cost loan schemes.

And of course, with mathematics what we were finding several years ago was especially our girls were seeing themselves as failures in maths, they were not mathematicians, they didn't like maths, didn't see the value of maths. We believe that through the implementation of STEM, and we've implemented STEM now for several years, we've had a huge turn around, female perception of themselves as mathematicians is extremely positive (Prog1B_P4_Int2b).

Only one principal argued there was no need to address equity issues in STEM education and that no provisions were needed for supporting students who might be underachieving in STEM.

6.3.1.3.2 Supporting others in the school

One principal noted that they had developed a more defined and focused leadership capacity, through the project, related to supporting teachers' capability with progressing students' problem-solving abilities. Similarly, another principal commented they had developed their STEM leadership capability by adopting a 'community of practice' approach when working with their Heads of Department. This had helped with strategic planning in relation to curriculum development and delivery.

Concurrently, other principals acknowledged the importance of seeing themselves as learners alongside of teachers in their schools. In this position, they believed part of their role was to present a positive and proactive attitude towards building the STEM capacity of all members of the community. This included a collaborative, ongoing dialogue with parents.

And I kind of just present it that way, in the sense that "You're learning, I'm learning, we're all learning together." If you want to call it distributive, I certainly tap into the other resources I've got within the school and have those people lead a lot of the PT that might occur. At the same time as bringing the staff along, we need to bring the community along as well (Prog1A_P5_Int2).

6.3.1.3.3 Generating new ideas

Principals outlined a number of strategies aimed at bringing new ideas related to STEM into the curriculum, including:

- the use of professional learning teams and communities,
- partnering with experts,
- investing in curriculum planning and unit design, and
- investing in STEM coaches and mentors, such as a 'scientist-in-residence'.

So, there's different staff that have attended different things. And we're definitely happy to get some experts in. We're looking at having a scientist-in-residence still, so we're looking into that to get that happening for next year (Prog1B_P8_Int2).

So, we're utilising the grant money that's coming from the Queensland government for progressing STEM in primary schools … to employ a capability coach within the primary school (Prog1A_P3_Int3).

6.3.1.3.4 STEM subject delivery

Other principals had developed new perspectives on how particular STEM subjects could be delivered due to PASL PL. One principal commented that she was not a mathematics teacher and so had not thought about the possibility of teaching mathematics in innovative ways until she had participated in the PL: she was now open to such possibilities. Another principal described how their new focus within school PL was on a whole-school problem solving approach that encompassed real-world STEM problems, something she felt was a real innovation.

> *Because I was not a maths/science teacher, I always thought that the way maths and science was taught, I guess put a bit of a blocker up for kids to enjoying it and it made it a very pure and clinical process and I always thought that, I guess, they know best. But I actually now believe that it doesn't have to be like that, and it shouldn't be like that, because there's no joy in it (Prog1A_P3_Int3).*

6.3.1.3.5 The importance of trust, vulnerability and transparency

Principals emphasised the importance of trust when innovating in their schools. Working with smaller groups, such as with lead teachers, to initiate innovation required inter-relational trust they saw as essential if challenges (such as changing pedagogy) was to be not only addressed, but embraced. Further, principals emphasised the need to "meet staff where they are" in terms of their STEM teaching practice development. They were aware of different levels of confidence/experience in relation to STEM that needed to be addressed. This included the provision of resources, such as digital technologies and associated PL.

One principal suggested that an adaptable approach was necessary to support teachers who were struggling to enact STEM change. Strategies to address this challenge included the deployment of STEM mentors who were available to work with teachers in their own classrooms. Some principals also believed it was important for teachers to learn alongside students, as the act of making themselves vulnerable enough to share their journey of learning to the school was beneficial to enforcing a STEM-positive culture.

Principals also stressed the importance of being transparent about future directions. Another important consideration was the sustainability of proposed innovations, which required careful strategic and financial planning.

6.3.1.3.6 Involvement in STEM school initiatives

Principal willingness to be personally involved in the development of STEM initiatives and strategic planning differed amongst schools. This appeared to be influenced by factors, such as a principal's level of engagement with/interest in STEM and, more broadly, their style of leadership. One principal realised after PASL PL Session 1 that she couldn't expect staff buy-in/engagement if she only forwarded communications: she had to actually lead by example and attend STEM events. Another principal took from the PASL PL that they needed to show presence in developing and implementing plans for learning within the school.

> *I now know that unless I start going to all of these things that I promote to the teachers that my impact is going to be minimal. So, it doesn't matter how much money I throw at them and opportunities and give them beautiful resources and things like that. What means the most to teachers is that you actually take a personal interest in them (Prog1A_P3_Int2).*

In contrast, another principal preferred to establish professional learning teams and to have the staff develop each other, while he took a 'hands-off' approach. This appears to have distanced the principal from what was happening 'on the ground'.

Yes, so my experience of leadership, - you know, the principal just has to be the catalyst. Just has to make sure to put the resources in place and trust that people will do things … I can't give you, I mean I've heard stuff but I can't give you specific examples but I'm certain I could go and find something and get them for you but certainly some of the things I've heard about - and looking at some of the assessment the kids have got to complete does, like, it requires kids to work at a very high level as well and it certainly has integration across the board, STEM-type stuff in it (Prog1B_P7_Int2).

6.3.1.4 Tools

STEM education requires the capacity to use physical tools (for example, models and measuring instruments), representational tools (such as symbol systems, graphs, maps, diagrams, drawings and tables) and digital tools (computers, robots and Internet of Things, for example). It is important, therefore, for principals to understand the role tools play in STEM teaching and learning and develop proposals for the acquisition of relevant tools as part of their strategic planning. Principals' reflections on this aspect of leadership after engagement with the PASL modules are detailed following.

6.3.1.4.1 Approach to tool acquisition

Principals reported becoming more critical, discerning, and strategic in their approach to the acquisition of and deployment of resources, especially in terms of digital tools. They attributed this to a better understanding of the role technological resources play in STEM, especially in developing problem-solving and critical thinking skills.

I think just in terms of confirming about, you know, the underlying thinking skills type stuff has been important. Also confirming [advice from modules about STEM implementation] it doesn't have to be all bells and whistles sort of stuff and that it is very much about problem solving, designing and that sort of thing and sort of lends itself very much to that thinking skills stuff that we're trying to do (Prog1B_P7_Int3).

Principals identified a number of factors related to their procurement of resources including concern for socio-economic equity; namely, that no child should miss out, and a concern all students should be engaged with STEM regardless of their levels of attainment.

To address these issues, principals reported working closely with their respective Parents and Friends (P&F) organisations to gain support for the acquisition of resources. These included human resources, as well as those associated with technology or the built environment.

We do have families that are definitely in the low socioeconomic band, but I suppose we would ensure that no child was disadvantaged for any reason … We have a very generous P&F, whereas if you're in a low socioeconomic school you're not getting that level of support (Prog1B_P8_Int1).

There was one instance, however, where a principal cited the lack of financial resources to justify limited activity in relation to STEM education.

And this school in particular, we're not a very wealthy school, we've been broke for years and our infrastructure and physical resources for digital technologies has always been low. So that's been a big issue and I think over the years our teachers that have been here a long time, they've got a mindset that "Oh, technology doesn't work at this school": (Prog1B_P5_Int1).

6.3.1.4.2 The role of tools/resources in teaching/learning

Principals appreciated discussing and learning about the role that various resources play in effectively supporting students' STEM development. One of these was Gapminder[13], an online resource, which produces free teaching materials that package factual, bias-free, global statistics and datasets in an easy-to-use format. Principals found this tool especially beneficial for teaching students to interpret data within real-world contexts.

> *We can't begin to tell you how powerful this has been. Like, it's been amazing. And the parents are talking about it! So, the kids are obviously going home, you know … loving that Gapminder thing. You've got your mathematics straight there and then. We didn't teach data separately or exclusively. We stopped and we taught it though* [the Gapminder activity]. *They didn't have a clue that we were teaching them how to read a graph. But gee can they read a graph now - and not your typical bar graphs! No, this was real-life stuff that they had to find out and they had to justify and then they communicated it (Prog1B_P8_T2_Int3).*

Other principals spoke about investment in significant infrastructure to support STEM education. This included learning environments that made advanced technologies (such as VR Space, 3D printers and laser cutters) to students and teachers. One principal reported that a risk with such investment was staff resistance to changing their approaches to teaching that would take advantage of these facilities.

6.3.1.5 Critical orientation

Principals' capacity to take a critical orientation to STEM education leadership is reliant on their willingness to form and make carefully reasoned, evidence-based judgements and decisions about the direction of curriculum and how resources should be deployed towards identified goals. This includes a preparedness to gather and analyse relevant data that informs the future directions of STEM teaching and learning in their schools. These capacities demand extensive and sophisticated knowledge, skills and capacities related to the effective leadership of complicated educational change. Principals' observations about this capability are detailed following.

6.3.1.6 Making judgements about how to support STEM

Principals indicated they had become more discerning about how they supported STEM education in their schools. For example, careful judgement and thoughtful decision-making was required about how to enact an integrated STEM curriculum while remaining aligned to Australian Curriculum requirements that were represented by separate discipline descriptions. One principal had decided to make use of a STEM coach to work with teachers in areas in which they felt less confident (typically, science or mathematics). The role of the coach was to model innovative approaches through demonstration lessons.

The issue of curriculum requirements related to separate disciplines versus integrated approaches to STEM appears to be greater in secondary settings rather than primary. One principal had planned to initiate a degree of STEM integration as a way of addressing the cross-curricular priorities in the Australian Curriculum, but had not found a way to introduce this to their secondary staff.

> *Having a look at the ACARA documents and doing a match with our planning because we ultimately want to move towards integrated studies of STEM but we're not confident we can do that until we're confident that the teachers really fully understand all of the details (Prog1A_P3_Int3).*

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[13] See www.gapminder.org

The challenges around integration are different in the primary context as teachers have up to eight areas of study to address on which to draw. This provides both opportunity (a range of different areas that might be drawn upon) but also challenge, as integration can requires deeper knowledge of a topic in order to see how it can be linked with others. A further challenge was teachers' reluctance to change the approaches they were currently employing they deemed to be successful. This reluctance rose out of concern that teaching in a different way might not be as successful; that is, they were concerned about the consequences for students if a new approach was unsuccessful.

> *We talk to them about an interdisciplinary approach or an integrated approach to teaching and learning of curriculum disciplines … and enable our staff the opportunity to embrace it and see how it can work without them worrying that they've taken the risk and it hasn't worked (Prog1B_P4_Int2).*

Principals also became more discerning in their decisions regarding the STEM PL that they and their staff attended. One believed it was important for staff to attend alongside the principal in order to develop a coherent direction for STEM learning in their school. They also saw a place for staff who were engaged with innovation in STEM education to run PL within the school.

> *I think it's important to send a big team, not just leaders to be going. We always invest in the staff going. And then staff can nominate for professional learning they want to attend externally and that's linked to their own professional goals (Prog1B_P8_Int1).*

They also noted it was important not to form judgements based on one experience alone. Possible directions were best considered over a period of time that involved conversations with staff about how an initiative would align with best practice. This sort of conversation was part of what principals saw as 'developing a shared vision'.

6.3.1.7 The use of data in decision making

A number of principals commented that the inclusion of a section on data literacy in the PL was helpful. In particular, this related to the sharing of data with teachers in order to support students' progress. In this case, data were used so that teachers became accountable to each other for ensuring positive learning outcomes for students. Principals also recognised it is key to track students' progress in the development of STEM capability. For example, one principal reported that, through the use of data, they had seen changes to the performance of girls and young women in mathematics and they could to link this to a greater emphasis on STEM education in the school.

> *Everyone owns and shares the data that we have. Each week the learning support team meets together … and so we look at those individual cases and we work out what's the best level of support (Prog1B_P8_Int1).*

6.3.1.7.1 Strategic approaches to planning

Most principals acknowledged the importance of collaborating and planning with teachers about future direction in STEM education and providing the resources they needed where possible. This planning included engagement in discussions about a sustainable technology plan.

> *What we have done now at the beginning of the year we've got a whole day about STEM. So, we're really going back to what's the vision, what's our shared understanding, and then looking at that framework [STEM Capability Sets] and seeing if it's something we can use. It's important when you have these new initiatives that you invest the time so it's going to be sustainable (Prog1B_P8_Int3).*

The complex challenges associated with STEM education initiatives meant that planning and implementation had to strike a balance between impact on teachers' workload and the introduction of innovation necessary for improved student learning outcomes. The management of this challenge required discussion about what was meant by innovation itself. One principal reported establishing groups of Department Heads to discuss what innovation meant to them in order to build consensus and then decide on future directions. Another principal reported that their approach was based on a STEM committee, which met to discuss what it saw as priorities that were then communicated to the school executive. The school executive then looked how these suggestions and proposals aligned with the school's strategic plan.

6.3.2 Teachers' Views of Principals' Leadership

6.3.2.1 STEM discipline and integrated knowledge and practices

Teachers commented on their principals' awareness of concepts, skills and practices related to STEM disciplines. Some noted the awareness of the range of careers that require STEM skills in their schools, or the role STEM plays in personal well-being, financial security and national economic prosperity. Teachers were generally positive about their principal's capacity to foster a STEM-positive school culture. The specifics of relevant perspectives are presented following.

6.3.2.1.1 Developing teachers' capabilities

Teachers noted that principals were promoting PL that 'unpacked' the curriculum in terms of STEM. They also commented on an increased focus on problem solving and critical thinking and that there had been greater attention to the resources that teachers needed to be effective in their STEM teaching practice. Other teachers mentioned the emphasis principals had placed on PL in developing teachers' STEM capabilities.

At the same time, the lack of teachers' comments on principals' understanding of STEM concepts, skills and practices was noticeable. This seems to indicate that discussions about STEM knowledge, central to STEM learning, were infrequent or that teachers did not think this capability was necessarily part of a principal's role.

While this observation is consistent with principals' interview data (in that they were relieved that they did not have to be experts in STEM), it raises questions about whether or not the promotion of a positive STEM learning culture is being driven by attention to pedagogy and resources only. This also brings the focus back to the level of expertise principals must acquire.

Principals were also seen to be facilitating conversations with staff aimed at enhancing the language and communication that supports STEM. Other strategies included teacher release time, a STEM honours programme and student-led STEM groups.

> *I can honestly say the principal has been very supportive of STEM learning and she has provided us with lots of opportunities to be released to work with staff and mentor them (Prog1B_P4_T1_Int2).*

6.3.2.1.2 Awareness of STEM careers

There was limited comment on the range of careers that require STEM capability; however, teachers understood the importance of preparing students for a future that would increasingly rely on a STEM-literate workforce. This was prevalent in teacher comments related to the changing workforce, and the need to address environmental and social issues. Teachers also noted their principal's attention to gender issues and STEM, and the importance of supporting female students to achieve in STEM.

Primarily I'm really aware of the gender issues there because ultimately it's the jobs within the STEM environment, and especially with mathematics stuff, that are going to provide financial security for our young women (Prog1A_P2_T4_Int1).

6.3.2.1.3 Developing a sustainable positive STEM culture

A range of approaches were used to promote a positive STEM culture, including:

- encouraging the autonomy of teachers,
- professional learning communities, and
- technology capability development groups.

Teachers noticed their school leadership was promoting STEM by showing genuine interest and targeting STEM initiatives through range of cultural programmes (such as Harmony Day, NAIDOC Week and STEM Fest).

Some principals promoted a sustainable school STEM culture through their support of teacher autonomy through PLTs. They also influenced student and parent attitudes through the promotion of STEM and community cultural programmes. Teachers also commented that school leadership was adopting the notion of problem solving from the Australian Curriculum to drive STEM culture in the school. Other teachers mentioned the importance of PL, initiated by their principal in developing their STEM skills. Another focus was on how to differentiate the STEM curriculum, depending on students' needs.

I really, I really love the leadership at my school. I've always appreciated the amount of freedom I've been afforded here and respect as a professional. There's been more opportunity for like for like engagement professional learning communities (Prog1A_P2_T2_Int4).

The principal has really pushed the whole idea of mathematics problem solving and how mathematics problem solving can cross over into the STEM world and to think of our STEM activities as mathematical problem solving as well (Prog1A_P2_T2_Int2).

6.3.2.2 Contexts

Teachers made a number of observations in relation to the context of their schools, including the capacity to develop a vision for STEM teaching and learning and lead sustainable educational change specifically allied to the culture of their school. They also commented on principals' responses to the demands and opportunities associated with national and state curriculum and policy requirements. Principals were also seen to have the capacity to promote STEM education within the school and to establish relevant partnerships with stakeholders within the school community. Teachers' observations on these themes and their representative comments are presented following.

6.3.2.2.1 Promoting a school STEM education vision

As part of the promotion of a STEM vision in the school, some teachers commented that their principals recruited specialist coaches (for example, technology leaders), while other principals initiated specific STEM programmes as a way of implementing their vision of what STEM might look like in their school. There were teachers, however, who were unable to identify the school vision for STEM or any initiatives that might indicate their schools' direction in the pursuit of a positive STEM culture.

The one thing I've really noticed in terms of STEM leadership is that we have a new STEM leader in the school. Having someone in that role that's really driven and is facilitating a lot of upskilling of us staff ... (Prog1A_P2_T2_Int2).

There were also teachers who noted that their principal had been actively promoting STEM by investing in infrastructure within the school. Additional strategies included STEM focused excursions and incursions. Other teachers commented there had been an increased level of communication about STEM from their principal, including opportunities for PL; however, there were some who noted the increased level of communication, but said there had been little by way of support other than offering limited PL events that were sometimes focused on how national/state curriculum was unpacked in relation to STEM opportunities within their school.

6.3.2.2.2 Promoting the school STEM education vision with the local community

Teachers identified a number of events which had the potential to establish networks and partnerships among schools, for example, STEM showcases to which other schools were invited. One teacher reported how their school established a network/relationship with a rural primary school and organised a STEM Expo where 'city kids' at their school could go and learn about agriculture/STEM within an agricultural context. The teacher commented that teachers and students had learnt a lot about networking with local industry and running effective STEM programmes for students. In some schools, however, it was left to individual teachers to establish partnerships with industry or experts in a relevant field. Other teachers commented that the work associated with the promotion of STEM was always left to the same small group of enthusiasts.

> *They put on their own STEM Expo had the industries come in, because a lot of them are farmers, or families in farming or transport. They explained the distances travelled by trucks and the crate, how much it can hold and that kind of mathematics. And they talked through the engineering and the kids got twenty minutes at a station, organics farm and irrigation. The kids were even talking about irrigating our plants out here (Prog1B_P8_T2_Int2).*

6.3.2.2.3 Responding to individual needs

A number of teachers appreciated being trusted and supported as autonomous professionals; for example, by being empowered to select resources they believed they needed for promoting STEM learning outcomes for their students. Responding to individual teacher needs can create the impression that decisions are not always aligned with a well-articulated strategic plan that provides guidance in relation to the acquisition of resources matched to the specific needs of a school. Other teachers commented on the increased support they were receiving in relation to PL attendance, but did not provide any sense of how this was aligned with school strategic goals or objectives.

6.3.2.3 Dispositions

Teachers commented on a number of aspects regarding what they perceived to be their principal's dispositions in relation to STEM. Most importantly, they noted actions that were underpinned by a belief that all students and teachers can develop/enhance their STEM capability. They also commented on initiatives that demonstrated their principal's openness to the implementation of innovative STEM teaching practices and their confidence that innovative STEM programmes can be initiated, managed and brought to fruition. Some teachers saw their principals as being supportive and encouraging of their engagement with the STEM project regardless of differences in levels of knowledge, skill and confidence. In general, principals were seen as willing to be personally and actively involved in establishing and sustaining the school STEM education programmes. A synthesis of teachers' commentary on their principal's disposition towards STEM education is presented following.

6.3.2.3.1 *Strategies for developing teachers' STEM capabilities*

Teachers commented on how the school had supported the development of their (and colleagues') STEM capabilities through a range of strategies, such as:

- support for professional leaning and encouragement to act as autonomous professionals and to see what other schools were doing;
- a measured pace for change, so as not to leave late adopters behind;
- encouragement to pursue further study in STEM; and
- the use of digital tools to enhance staff communication.

One teacher also noted a new focus on how to differentiate the curriculum and assessment so that all students could achieve in STEM.

6.3.2.3.2 *Principals' confidence in staff and shared leadership*

A number of teachers indicated they felt their principal was confident in their capacity to take STEM forward in their classrooms and praised their ability to collaborate with school leaders and teachers. This confidence extended to empowering STEM leaders to enact and be accountable for STEM changes within the school environment.

> *We are really lucky because the principal has just provided us with so many opportunities. He has sent two members of staff and a group of five students to a Singapore annual learning conference which relates to STEM. In addition, I had all the key learning areas related to STEM released for multiple days of planning time. He is providing us with absolutely any and every resource. But he's also being involved in the conversations and doing the research and sharing the knowledge (Prog1A_P4_T2_Int3).*

In contrast, there were some teachers who felt they had been more instrumental in effecting STEM change than the principal.

> *It's been a lot of hard work on my part I think because we have actually, the school really didn't have their foot in technology for whatever reason for a couple of years before I came on the scene (Prog3_P5_T1_Int3).*

6.3.2.3.3 *The role of mentors and collaboration*

Teachers commented on how some principals had facilitated a collaborative environment where everyone was learning together. There had been particular support for teachers' uptake of new technologies. Other teachers described how their principals had recruited STEM coaches to support/coach/mentor teachers in technology and integrating STEM into units. This was seen as an adaptable approach to support different levels of teachers' confidence and skill. Another strategy that teachers noticed was the provision of 'release time' for key teachers so they could work with colleagues. Teachers were positive about principals' approaches that were based on a measured introduction of initiatives, thereby allowing everyone to get onboard.

Other teachers commented on the need to develop plans that allowed for flexibility in classroom approaches to STEM instruction in order to accommodate student differences and teachers' specific expertise. Different approaches were supported, providing the same learning outcomes were achieved.

I guess it's just we've been a lot more focused on getting the planning down. You know, in the busyness sometimes it can slip past. We've made a conscious effort to plan collaboratively the first part of the unit planner, but then realize [sic] that each class within a grade can be different in the way they deliver the material as long as the outcomes are still being achieved (Prog1A_P3_T8_Int3).

6.3.2.3.4 Different forms of principal involvement

Teachers reported that school leaders took different approaches to their involvement in STEM initiatives, including:

- actively encouraging teachers' participation in PL;
- supporting teachers' efforts through the provision of resources accessed through the school network;
- facilitating STEM related excursions and incursions; and
- modelling technology active pedagogy when working on a real-world task.

In contrast, other teachers commented that the approach to STEM in their school was "patchy" and that further sharing was needed.

I think we were getting there this year, but we hadn't nailed it. Like we didn't feel like - we were really doing bits. It was bitsy. And we sat there for weeks and weeks and weeks because they just could not identify a real-life problem (Prog1B_P6_T3_Int3).

6.3.2.3.5 Tools

Teachers commented on how they saw their principal's approach to the role of tools in STEM education. An important aspect of principals' leadership is their capacity to identify and procure resources that support effective STEM teaching and learning within their school context. Tools were seen as a means to an end; for example, the development of critical thinking capabilities. Teachers' observations about these aspects of leadership are presented following:

6.3.2.3.6 Tool acquisition and use

Teachers could see how the promotion of digital technologies in their schools was not an end-in-itself, but a means of promoting problem solving and critical, inquiry-based thinking. This sometimes extended to whole working spaces that required significant infra-structure. This sort of innovation could target interdisciplinary learning, but was sometimes directed at specific learning areas, such as mathematics.

I was tasked with the challenge of setting up this innovation centre/STEM hub so did a fair bit of research around how STEM works across the world, across Australia. One thing I do enjoy about the digital technologies' curriculum is that it is very project based. When we've done the STEM things we've really focussed more on an inquiry-based approach (Prog1B_P6_T3_Int1).

Most teachers were aware of how resources were funded (such as through Parents and Friends organisations); however, some indicated that sometimes resources were purchased without a discussion with staff about how they were to be used or how they aligned with a specific plan. Other teachers reported that their principal simply took the advice of individual staff members when procuring resources. While this is indicative of a high level of trust by leaders in teachers' knowledge and awareness of students' needs, this gave the impression that the acquisition of resources was not always aligned with a clearly articulated strategic plan.

Well, we were given absolutely free reign … So, completely financially supportive. Having some sort of a whole school approach I guess has worked. Whereas for me I sort of wanted to find my own tangent to make something with (Prog1B_P4_T2 _Int2).

6.3.2.4 Critical orientation

Teachers offered their perspectives on how their principals formed judgements and made decisions in relation to STEM education initiatives in their school. This included their reasoning processes and use of evidence in progressing STEM teaching and learning. In some cases, teachers commented on how principals gathered and analysed relevant data to inform future directions. This commentary provided insight into the knowledge, skills and capacities required to lead complicated educational change effectively.

6.3.2.4.1 Forming judgements about directions for STEM education development

Some teachers provided comments on the clarity with which their principal had communicated the evidence informing their judgements and decisions around STEM leadership approaches. Others identified the opportunities that had been provided to collaborate with their principal around the curriculum planning needed to develop an integrated STEM programme.

When I sat down with [the principal] and we pulled the Australian Curriculum apart, because it's in bands, we discovered that we had teachers teaching the same thing over and over. So, we started to build a scale of what technology would look like and it planted a STEM seed (Prog2_P4_T1_Int1).

6.3.2.4.2 Use of data to determine the effectiveness of STEM programmes

Teachers were also aware of how they could use standardised data (particularly for mathematics), to inform principals on the effectiveness of their STEM programmes. Those who attended the PL with their principals also described how their thinking had shifted in response to the data literacy module.

I think the shift that I've really learned lately is around data literacy. The PD yesterday was further on that and going "they need a lot more of that". Those sort of skills, that's what I love about STEM, the general capabilities, they're often missed. Doing STEM, I think the way that I've started thinking, is trying to hit those general capabilities as opposed to ticking boxes in curriculum areas (Prog1B_P6_T3_Int3).

While teachers noted the use of data in schools for tracking students' development in areas, such as numeracy, they also commented that this should only be one component of the evidence brought together to make decisions about teaching programmes with teachers' classroom observations as important. The question must be raised about how these two types of data can be integrated to provide an overall picture. Teachers also noted the barriers to utilising data tracking, such as time limitations, although they could see the benefits of using data.

There's data that we're tracking. I suppose in STEM, maths is the only data aspect that we would have monitoring data sets for. But obviously teacher's observations of their own assessments is just as important in how they monitor and do that as well. In my experience in schools, both in NSW and here, there's been a big focus on literacy and numeracy over the last few years at the detriment of the other subjects (Prog1B_P8_T2_Int3).

6.3.2.4.3 *Awareness of principals' approaches to STEM leadership*

In general, teachers were able to articulate their principals' approach to leading STEM educational change, particularly regarding curriculum changes, pedagogical approaches, building teacher capacity and resourcing.

> *Any curriculum, or any educational leadership, is not just about delivering the toys, but is actually to ensure that there are educational outcomes happening. A lot of staff would believe that the leader's role is to make sure that they are well resourced, which is very important. But it's also to make sure that they answer the question of "is this the best use of this resource or this money? (Prog3_P6_T3_Int2).*

However, some teachers did not seem to be aware of their principals' efforts in relation to STEM, except for incidental reports in the school newsletter.

6.3.3 Concluding Remarks on Results from Interviews

In relation to STEM discipline and integrated knowledge and practices, principals indicated that their involvement with PASL had clarified their understanding of STEM education and their roles as leaders of STEM education. They also reported deeper engagement with the challenges of interdisciplinary approaches to STEM education and the need to focus on developing staff capability, rather than the acquisition of resources alone. That said, it was apparent they had started from different positions on a continuum of discipline-specific knowledge and technical understanding. Some principals expressed relief that leadership in STEM education did not necessarily require deep discipline/technical knowledge.

While there was evidence that principals could generate positive STEM cultures within schools without a deep understanding of STEM discipline knowledge, this also raises the issue regarding the degree of STEM knowledge is needed to be effective as a leader; that is, how much does a principal need to know in order to be capable of asking the question necessary to make the best decisions about resource acquisition or relevant staff professional learning? Another area in which principals appear to have less grounding was knowledge about the nature of STEM careers and possible pathways towards toward student aspirations in this sector.

Principals reported that they had become more aware of the importance of understanding their school's context. Their capacity to develop a vision for STEM education that all staff could communicate to the school community was identified as key to promoting a positive STEM culture. There was sometimes a tension, however, between their responsibility to accommodate local needs and the strategic requirements of their school system, as well as the demands of local and national curriculum documents. Part of developing STEM education within a specific school context was establishing partnerships with the school communities locally, with school systems and sometimes nationally and internationally. Just as importantly, principals were aware of the need to plan for flexible and sustainable change. Teachers endorsed the need to generate and promote a STEM education vision that was informed by local needs, as well as highlighting the importance of principals' confidence in teachers' capacity to support this vision and respect for their autonomy as professionals.

The importance of principals' dispositions towards generating a positive STEM education in schools was evident in their commitment to developing every students' STEM capability; that is, an issue of equity. Principals took different approaches to inspiring students' interest in STEM, including attempts to create different ways to engage students with STEM through, for example:

- the initiation of staff professional learning teams;
- partnering with experts, such as scientist or mathematicians; and
- investing in STEM coaches and mentors to ultimately inform curriculum planning and subject delivery.

To be effective in facilitating change, however, principals emphasised the importance of demonstrating trust, vulnerability and transparency. Most also indicated they understood that their personal involvement in decision-making was key, although there were instances where principals deferred the role of their school's STEM strategic planning and implementation to individuals or teams of teachers. This approach brought with it the risk that principals could be seen as distancing themselves from the actual progress of schools' STEM education goals. Teachers commented they recognised this risk and indicated they believed the role of principals in STEM education was key.

Another important role for principals was the management of school resources, including the appropriation of STEM tools. In general, these tools were focused on digital tools (for example robotic technologies) or school infrastructure (the built environment). Principals reported that they had become more discerning over time with a shift from considering the tool itself, to how it would be used to promote problem-solving and critical thinking capabilities. Additional factors that were considered when considering the acquisition of resources include issues of equity ('no child should miss out') and a concern for how all students can be involved in STEM education, regardless of their previous records of attainment. How such aspirations were realised, however, sometimes resulted in a conservative approach to promoting STEM education. Teachers supported the notion that the acquisition of resources should not be an end in itself and it was important that the purchase of STEM tools was connected to broader educational goals. At the same time, some teachers indicated that specific educational goals were not always made evident.

Principals indicated that they understood the need to take a more critical stance in relation to how they supported STEM education in their schools. This was particularly apparent in their decisions about how to introduce more integrated approaches to STEM education in their schools and in the use of data in decision-making. Taking a critical stance impacted on their strategic approaches to planning that included how they collaborated with teachers in charting future directions for innovation within their schools. While principals indicated that strategic planning was vital for the progress of STEM education, the notion of being critical was a capability that appears to require further attention in their professional learning.

6.4 Change associated with participation in PASL PL

This section is a description of principals' perspectives on how key aspects of PASL PL programmes have influenced their thinking and/or action in relation to developing a positive STEM culture within their schools. These changes are related to:

- understanding the nature of STEM;
- the role of the Capability Sets;
- curriculum opportunities;
- new perspectives on pedagogy;
- use of data;
- leadership and culture; and
- additional comments on the programmes/modules.

6.4.1 Understanding the Nature of STEM

Principals reported they had developed a better understanding of the nature of STEM and were now able to articulate their school's vision for STEM education, which was now included as a statement within their digital technologies policy.

Within the PL session we discussed some ideas and I took notes and wrote down a few little things through there. The major one is that we believe we've got to find a vision statement that encompasses everything. So that was my main aim (Prog1B_P5_Int3).

Principals also noted that PASL PL had provided insight into models of integrated learning, which they were able to present to teachers in their schools. In some cases, engagement with modules confirmed schools' approaches to integrating STEM and incorporating digital technology.

The PD just confirmed that we were heading the right direction. Because already this year, the teachers, each semester, they design an integrated unit of work, based on STEM and incorporating digital technology. And that has been very successful because we've employed an ICT coach that helps them when the technology fails (Prog1B_P1_Int2 [edited]).

Further, PASL PL had instilled confidence that STEM education must involve all in the school, helping them to generate contexts for learning experiences in which the whole school could contribute, for example, those working within the arts.

6.4.2 The Role of the Frameworks and in Particular the Capability Sets

Principals found the Capability Sets presented in the modules were useful as an organisational framework to structure their own thinking and for framing discussions of the development of a positive STEM culture with staff.

One principal commented that the cross-cultural audit was a useful supplement to the Capability Sets. Another commented that they were using the Capability Sets as an ongoing reference as the school developed its vision for STEM education.

So, I use your Power Points all the time. They sit here in my inbox tray, so I can access them whenever. And, just to reflect back to some of the thinking diagrams and stuff that you had. I guess, I just use them as a reference document (Prog3_P1_Transcript_P1_Int2).

Sounding a note of caution, one principal (who made the point that the danger in presenting too many frameworks was the potential consequence of introducing conflicting ideas – something with which they struggled) believed there was always a 'right and wrong way' of progressing an initiative.

6.4.3 Curriculum Opportunities

Principals commented that PASL PL helped clarify their schools' approach to STEM in relation to the curriculum. In particular, the PL highlighted opportunities of the different ways STEM could be enacted in the curriculum. For some principals, PASL PL prompted a change in expectations related to school curriculum and STEM. An important difference was the focus on deep learning and new ways of thinking that should be embedded in STEM activities.

I think my expectations have changed. We have a tendency to use the word "STEM" a lot maybe without the deep thinking and learning behind it. The question is how can those two subjects be linked, or three or four subjects be linked, with quality activities? If it's STEM, that it might just be math and science, or it might be engineering and science, or it might be engineering and math (Prog1A_P1_Int2._SAA).

PASL PL resources were seen by some principals as useful for scrutinising the core learning elements, scope and sequencing of the Australian curriculum, and developing a learning plan for the whole school. This helped to clarify how STEM can be incorporated as part of a whole teaching and learning programme. PASL PL gave one

principal the permission to provide teachers in their school with the freedom to develop new ideas without feeling constrained by the Australian curriculum.

> *Having gone through the project, I want to look at "what is the core?" What is the core learning that we're looking at for this? And if we're saying that it's through science, technology, engineering, and maths, what does that look like for a foundation teacher? So, we've got some of the documents from the PD around the scope and sequencing of that from the Australian Curriculum and some of the other resources (Prog1A_P1_Int2).*

There were principals who commented that PASL PL challenged their thinking about STEM assessment and required them to consider the question: "where does STEM sit within assessment programmes?"

6.4.4 New Perspectives on Pedagogy

Principals found PASL resources were helpful in the development of their schools' pedagogical framework, such as modules that informed their approach to inquiry, scope and sequence, planning inquiry units. The PL resources also highlighted considerations of validity and assessment priorities.

The material in the PL modules (such as the growth mindset information) directly informed one schools' approach to age-appropriate pedagogy. Other materials, such as PASL PL project-based learning information and concept mapping approaches, were also beneficial for clarifying principals' thinking and planning for STEM and inquiry-based learning. PASL PL materials were also useful in relation to planning for pedagogical approaches, as they provided clarification on the distinctions between digital technology and STEM.

6.4.5 Data

One area of interest to principals was how material in the PASL modules inspired new ideas about ways they could incorporate the use of data into their STEM activities was. For example, they found the Gapminder activity useful as a means of generating problematic scenarios in the real world that students could seek ways to address.

> *One of the things we did in the PL was to look at some data around climate change and how you might use data to try and get a picture of what's happening and fiddle around with the variables and get different sorts of outcomes. It's how you use the mathematics content, for example, to address a real-world issue and then come up with solutions. That's something that you could do it in math class or a STEM class or geography class (Prog1A_P3_Int2).*

The PASL PL module devoted to the use of data was viewed by principals as useful, as it helped open a discussion on how data was viewed by different stakeholders in education. Some principals commented that PASL materials on data had informed their schools' data usage and technology policy. Other principals noted the potential of using data to inform their directions in teaching, learning and assessment.

> *It was really important to get some of the data around and statistics around STEM and where STEM sits in the national political framework in our country. That sort of information is really important and valuable to our teachers because we need to know the direction and where to point our students. This is an important issue for our country, for our economic sustainability and our future (Prog1B_P4_Int3).*

Only one principal commented that they did not find the materials on data useful as there had already been a significant focus on this topic, in their state.

The second session, we were looking at data. I didn't find this session to be that much use. In Victoria we have a lot of PL around data, so I know that the framework's been designed to be national but in the Victorian context spending half a day on data wasn't really that useful (Prog1A_P3_Int2).

6.4.6 Leadership & Culture

Principals commented on how the PASL PL resources had been useful for informing the leadership of deputy principals and assistant principals. This was seen particularly in relation to the appointment of appropriate teams that would progress the STEM agenda and consideration of the structures schools needed to develop in order to support the work of STEM learning specialists already in place. In particular, principals commented on the PASL PL module relating to school culture and change, which prompted them to think about its relevance to their school. Others found the PL modules on change management and governance were helpful, especially the advice about how to promote staff engagement and buy-in.

Some principals found the resources related to models of leadership the most helpful; for example, relational versus transactional.

What has been beneficial has been the work that happened around the leadership models and the leadership discussions. It has an application to STEM. I've been pursuing some of that stuff around that relational, translational, relational leadership because it's significant if we're going to move people into this innovation, inquiry, or into STEM-type units (Prog1B_P7_Int3).

There were principals who found that the modules on leadership confirmed their understanding of what good leaders do to, that is:

- effectively leading change in schools;
- making STEM current/front and centre;
- promoting collaboration with teachers around integrated STEM; and
- celebrating successes and generating positivity.

I love the leadership [module] was a confirmation of what good leaders do and how to drive something to get it going in the school. Setting aside time on the school development days to work, including teaching performance management. Keeping it front and centre in people's minds, celebrating in the sense of highlighting. It generates positivity around it rather than negativity, which sometimes can be a problem with new initiatives (Prog1B_P1_Int2 [edited]).

Only one principal did not feel the leadership material was relevant due to their extensive experience; however, they conceded it might be useful for STEM learning specialists or for younger colleagues.

I've been in leadership for over 10 years, so it just wasn't relevant to me. For STEM learning specialists, for the younger people, I think that might have been more relevant, but for me it was just like "You know what, I don't want to hear this. I've already formulated my own leadership" (Prog1A_P2_Int3).

6.4.7 Additional Comments on Programmes/Modules

In general, principals appreciated:

- having a specialist PASL facilitator;
- the connection of theory to practice presented in the modules; and
- collegial conversations with other principals.

> *Number one, we had a specialist person who was teaching and sharing there, and I found that what they shared to be very, very helpful. Number two was the research-based evidence that they provided, either through the PowerPoints, or through the content, or through the conversation that we had. And number three was in the collegial conversations that we could have with other principals as they were sharing about what was happening in their schools (Prog3_P1_Int3).*

Other principals appreciated the inclusion of templates and models of STEM planning documents and the national STEM resources in modules. A number of principals commented that the resources provided some insight into how to embed ATSI perspectives/culture in a meaningful way in STEM, in a sustainable and ongoing way.

Principals also found the PL information on what industries are looking for when employing people useful.

> *One of the data sheets from the PL was around what industry are looking for employment. And I thought that was very telling in that it referred to the fact that what people really wanted, surprise surprise, was collaboration and teamwork over actual expertise and STEM qualifications for their employees. And I think that says it all (Prog1A_P2_Int2).*

6.4.8 Concluding Comments on PL Change Module Specifics

Principals indicated they had developed a better understanding about the nature of STEM and the different ways in which integration can take place within planned and enacted curriculum. While the material presented in modules was new to some principals, for others it was a welcome confirmation of the approaches they had already initiated in their schools. Their understanding of STEM had enabled them to more clearly articulate their vision of STEM education in their schools. An issue raised by a small number of principals was the number of different STEM-related frameworks that were available. In these cases, principals appeared to be looking for the 'right way do STEM'. At the same time, other principals argued the modules had given them permission to be more inclusive of teachers of subjects not considered part of STEM, as a transdisciplinary model to also provide flexibility in what knowledge could be brought to bear to solve a problem.

The STEM Capability Sets were seen as a useful organisational framework for reflecting on principals' roles in promoting a positive STEM culture in their schools. Other frameworks, such as the cross-cultural audit tool, were also seen as helpful. In general, principals indicated that they appreciated access to tools that helped them structure their thinking about STEM and its implementation in their schools.

The provision of resources related to how STEM can be enacted in different ways with a school curriculum was seen by principals as opening up opportunities within their schools. A particularly important difference was the message to focus on deep learning and new ways of thinking for students when engaged in STEM activities. An additional benefit was that PASL resources had providing the means to scrutinise the core learning elements, scope and sequencing of the Australian curriculum in order to develop a learning plan for the whole school. Engagement in the programme prompted some principals to consider how assessment needed revision in order to accommodate the changes they were making to STEM education in their schools.

Principals indicated that PASL module materials had helped them think about new approaches to pedagogy that should be considered within their schools. Resources (such as those associated with Growth Mindsets[14]) were used as catalysts for discussion about age-appropriate pedagogies. Discussion around pedagogy also helped some principals to understand the role of digital technologies in STEM education. One principal raised the issue of how children with disabilities could best be supported within STEM education, as a matter of equity.

[14] See https://www.mindsetworks.com/science/

PASL materials related to data was seen by principals as helpful in three ways, by:

- providing new ideas about how data could be incorporated into STEM activities;
- providing ways in which data could inform their future directions in STEM education; and
- informing discussions with school stakeholders about STEM education in their schools.

There was only one principal who did not find materials around data literacy helpful as they had been involved with significant professional learning on this topic, in their state.

Resources related to school leadership and culture were seen by principals as helpful, particularly in relation to how educational change can be managed in a positive manner. This included advice on how to promote collaboration with teachers in bring STEM education initiatives to fruition and the importance of celebrating success.

Principals commented on other helpful aspects of the programme, such as:

- having a specialist PASL facilitator;
- the research presented in the modules, especially the connection of theory to practice; and
- the collegial conversations with other principals.

Others appreciated the availability of templates and models designed to support STEM planning, commenting that these were not always available via their systems. Principals also indicated that the inclusion of ATSI perspectives had informed thinking and planning on this important area in their schools. Finally, some principals indicated they appreciated information on STEM pathways for young people who wish to enter STEM-related fields in their careers.

7 Case studies of practice

7.1 Introduction

Case studies of schools exhibiting exemplary practice in STEM teaching and learning were the focus of this study. The purpose of undertaking the case studies is to document innovative and effective leadership of school wide teaching and learning practice in STEM education.

This chapter provides a summary of each case study and a cross-case analysis, highlighting aspects of exemplary practice that are pertinent to individual cases or shared across cases.

The cross-case analysis drew from evidence from each of the case study schools, which is summarised and coded under thematic headings and then within themes across the cases. Included in these summaries are brief citations drawing from the primary data to both exemplify practice and to highlight commonalities and differences between the studies. These citations are referred to by codes relating to the schools (see following) and the data source (such as the principal, teachers or students).

In this chapter, a fifth and different type of case study, which was conducted within a state-based educational system, the Western Australia Department of Education, is also provided.

7.2 The Case Study Schools

7.2.1 Recruitment and Descriptions of Case Study Schools

The PASL project originally planned to identify case study schools from each region (inclusive of each state/territory) across Australia (*n*=7); however, due to the subsequent impact of COVID-19, only four case studies of schools identified as exhibiting exemplary STEM practice were conducted. A fifth case study, selected purposefully to investigate a system-wide approach to support STEM teaching, learning and leadership, was undertaken in Western Australia. The latter was also conducted with the aim of exploring the elements of successful mentoring of school leaders.

Case study schools were nominated from systems – Government, Catholic, Independent – as innovative designers and enactors of STEM active curricular, and were:

- Cerdon College (CC), New South Wales;
- Australian Science & Mathematics School (ASMS), South Australia;
- Hagley Farm Primary School (HFPS), Tasmania; and
- Brookman Primary School (BPS), Western Australia.

These schools represent a range of demographics; for example, high and low SES, metropolitan, Government, Catholic and Independent, rural and remote, primary and secondary.

The purpose of these case studies was to document innovative and effective leadership of school wide teaching and learning practice in STEM education that may not have been captured by the PASL literature review or

desktop audit. Additionally, the case studies provide a 'what is possible?' insight into whole of school, principal-led STEM education, as this is mediated by the specifics of school educational environments. The diversity of school case studies will enable resonance for the following:

- Location – a range of capital city, regional, rural and remote schools.
- System – including Government, Catholic and Independent.
- School type – single sex, as well as primary/secondary schools.

7.2.2 Introducing the Case Study Schools

Cerdon College (CC) is a Catholic all-girls college (Years 7-12) with a reputation for STEM leadership and learner engagement with STEM. The college has a multicultural student population, with 80% from non-English speaking background and varying socioeconomic backgrounds. The college has had a stable leadership since 2006 and has enjoyed some level of autonomy in the diocese due to successes (such as, high rate of graduating students and high levels of student performance at university) they have attained over the years. As a way of sustaining its practice, it has maintained ties with schools around the world and takes opportunity to experience 'how people do things differently'.

The school was staffed with teachers with diverse expertise, who are crucial to exploring and expanding STEM opportunities. Teachers are considered learners as they ascribe to a culture of learning throughout the school. The school has adopted an integrated approach to teaching and learning. While they used STEM based curriculum, they also relied on a range of extracurricular STEM activities, such as Lego club. Extra-curricular STEM opportunities were equally essential to the core curriculum at the college. The principal encouraged a blend of old and new technologies (such as textbooks, tablets and robots) to encourage and enhance STEM engagement.

POSITIVE AND/OR UNIQUE FEATURES OF CERDON COLLEGE

- Holistic approach to education promoting a balanced approach to both academic and social outcomes.
- Strong sense of unity and vision for STEM, supported by a distributed leadership model that empowers staff in localised decision-making, reflecting their first-hand knowledge of students.
- The school is founded on religious values with a mission to educate females to the best of their potential in all areas of learning and social conduct.
- STEM extracurricular activities have become institutionalised [such as Lego and coding clubs, participation in external STEM competitions and engineering challenges]. Includes a strong focus on gifted and talented mathematics.
- Engages in school-university partnerships, including senior students working alongside university scientists and researchers.
- Active and regular participation in STEM-related excursions.

The Australian Science and Mathematics School (ASMS) is a public secondary school that caters for students in Years 10, 11 and 12. It was established in 2006 with a strong focus on innovative science and mathematics education in South Australia. The school is located within Flinders University campus and shares some of the university's facilities.

The school adopted 'the whole school approach' to learning and teaching and emphasised strong partnerships between teachers, students, and the community. The school staff referred to their curriculum as an 'interdisciplinary curriculum', and while they did not refer to subjects as STEM subjects, STEM was incorporated where appropriate to the focus of study. Ongoing professional learning and mentoring opportunities were provided to teachers.

Students' admission to the school was based on their interest in pursuing science, mathematics, and related technologies career pathways (and not necessarily on academic attainment). This approach to admission was important for the functioning of their unique self-directed teaching and learning environment, which enabled and supported a high degree of student choice in their study. Investments have also been made in physical school spaces that were designed to support the ways students and staff work within them (self-directed learning). This included many open space classrooms known as learning commons, equipment-filled studios and laboratories.

POSITIVE AND/OR UNIQUE FEATURES OF THE AUSTRALIAN SCIENCE AND MATHEMATICS SCHOOL

- The ASMS offers students an 'interdisciplinary curriculum' delivered via Central Studies units, in which science, technology, maths, English and history are embedded.
- Teachers with different specialisations plan, teach and assess Central Studies units. This may entail, with appropriate support, teaching new content outside of their specialisation.
- Location adjacent to a university campus provides opportunities for students and teachers to learn from university STEM experts.
- The school is recognised for its excellence and offers PL and support for schools and teachers throughout South Australia.

Hagley Farm Primary School (HFPS) is a Primary School (K-6) with a focus on agricultural education, due to its location within a large government-owned farm-school complex. The school managed the farm (now commercially viable) and the Field Studies (Visitor) Centre (VC), which focusses on animal awareness, the farm environment and heritage. The VC is open to visiting school groups from around Tasmania.

With relatively new leadership, the school was in the second year of implementing the Tasmanian Food and Fibre curriculum. The implementation of this curriculum was led by an Advanced Skills Teacher who worked with classroom teachers to enable purposeful learning and curriculum connections in STEM. These learning activities took place both in the classroom and outdoors; on the farm and at sites within the school grounds. To support her plans for STEM education, the principal had invested in human resources that, in addition to the Advanced Skills Teacher, included an agronomist, a cook and a new farmer to manage the farm school. This investment was achieved through the Tasmanian Government's Revitalising School Farms initiatives.

The school was deeply connected with the local community; community members continued to be involved with the school, even if their children were no longer students at the school. Community engagement was encouraged, and the school used social media, especially Facebook, to disseminate information about school activities to parents and community.

POSITIVE AND/OR UNIQUE FEATURES OF THE HAGLEY FARM PRIMARY SCHOOL

- Ideal location for the exploration of regional and rural STEM supported by a state government commitment to enhancing agricultural education (such as, the Food and Fibre curriculum).
- Embraces a belief in holistic education that embraces all aspects of the life of the child.
- Entrepreneurial approach to achieving STEM vision through chasing opportunities; securing funding; and experimenting with ideas not traditionally educational (for example, 'Paddock to Plate' learning).
- Designated Advanced Skills Teacher role to progress STEM plans.

Brookman Primary School (BPS) is an independent public school that has been involved in STEM for six years. It drew from a diverse mix of students, with one third of them having English as an additional language.

The school was recognised for its leadership in STEAM across the Perth metropolitan area. Teachers tended to be facilitators of learning and adopted an integrated approach to teaching; hence, the focus extended to STEAM rather than purely STEM. To foster collaboration, the school instituted extension programmes in mathematics called the 'Genius Hour' and 'Techno Geniuses'. A key goal of these initiatives was to educate students (Years 4 and 5) to become adept at technology so they can actively support teachers with their use of technology in class.

Having an entrepreneurial principal, one who is able to secure funding and establish beneficial partnerships with external organisations, has been a key to the school's STEM agenda. He has invested the funding he has obtained in both physical and human resources. For example, professional learning for staff was an ongoing and embedded activity, and the school has a well-resourced facility called the 'Maker-space Room' for STEM projects. In addition, there was emphasis on community engagement, as parents and other stakeholders are seen to be important for students' education.

POSITIVE AND/OR UNIQUE FEATURES OF THE BROOKMAN PRIMARY SCHOOL

- Have become a STEM Teacher Developing School and participating in mentoring with other differently capable schools.
- Interdisciplinary (encompassing STEM), integrated and contextually relevant studies are part of the school's DNA.
- Entrepreneurial approach to achieving STEM vision through chasing opportunities and securing funding.
- Strong relationship with an adjacent high school to enable extension programmes for STEM outside the classroom.
- Has made resourcing a STEM a priority. The resourcing revolves around providing adequate PL experiences, materials, and importantly ways to store, access and transport those materials.

7.2.3 Cross Case Analysis of Case Study Schools

The set of cases were examined for evidence related to themes that aligned with issues addressed in the interviews, while allowing for others to emerge.

7.2.3.1 Perceptions of STEM

Each of the case study schools has developed a vision for their approach to STEM education; visions and pedagogical approaches that differ from each other, but which are aligned in their focus on enabling all students to actively engage in STEM learning that was relevant, authentic and attainable for all. Student-centred inquiry was central to each school's pedagogical approaches.

At CC, STEM was viewed by teachers, students, and the principal as multi-faceted, authentic, integrated, and complex. STEM learning and teaching were integrated with key shared beliefs that included:

- the notion of 'failing forward' (that is, failure is seen as a necessary part of the learning experience);
- both curricular and extracurricular opportunities should, however difficult they are, be open to all students;
- teachers and learners can (and should) learn in partnership;
- no one approach can work for all students at all times; and
- stable leadership fosters trust and supports long-term change.

The ASMS maintained a strong inquiry pedagogy focus with teaching for effective learning (TEFL) the guiding pedagogical framework within which the school operates. Pedagogical practice is underpinned by a learning design statement based on the key concepts of connection, coherence and agency. The ways teachers taught integrated STEM within their lessons was largely predetermined by planning teams. Teachers of Central Studies taught interdisciplinary units and assessed in all curriculum areas, including those outside their own specialisations. It is the nature of the inquiry which determined which of the four STEM disciplines and/or their integration were drawn on by students.

At HFPS, STEM was perceived as encompassing the development of discipline knowledge (particularly technology) skills, such as inquiry, problem-solving and collaborative learning, and pedagogical practices and learning activities. The development of these capabilities was centred around problems that could be explored within an agricultural context. The context was key to students' engagement in STEM as the school drew heavily upon the surrounding farmland, animals and heritage facilities.

BPS had developed a broad understanding throughout its staff around the expectation of STEM education within the school; namely that students engaged in a minimum of one STEM project every term. The school embraced project-based STEAM (incorporating Arts). These projects fostered skill development in creativity, independent thinking, critical analysis, problem-solving and teamwork.

Leadership

Unsurprisingly, strong leadership was identified as a crucial aspect of each of the case study schools. Two types of leadership styles were evident in the data and each is discussed in the following sections:

- visionary leadership (Taylor, Cornelius & Colvin, 2014), and
- entrepreneurial leadership (Renko, El Tarabishy, Carsrud & Brännback, 2015).

Each case study school identified a vision for STEM education that was documented and (according to the principals) shared and made clear to all. School leaders worked with their teams to ensure that the vision became

a reality in the school. This vision was usually codified in a vision statement, which was articulated by the leader who drove the actualisation of the vision themselves.

> *We've got a really clear vision around our learning at the school. So it is, the vision is extraordinary learning driven by curiosity and challenge and inspiring confidence and passion. So that drives our work, that captures what you just asked the students to do, is actually what we live for and breathe, I hope. Here (ASMS) is providing opportunities for students to be curious and to work together to try and come up with their perspectives, or their solutions and their ideas (principal, ASMS).*

School leadership styles were also identified as 'entrepreneurial', a term used to describe leaders who have a business-like orientation. In the case study school settings, such a style was evident in the way in which principals harnessed opportunities for funding, collaboration, and partnership.

7.2.3.2 Gaining financial support for investment in resources

For effective STEM practice the availability of appropriate resourcing and resources is essential. These resources comprise both human and non-human resources and the principal is responsible for 'obtaining' these resources. To achieve their STEM vision, case study school principals and their leadership teams allocated sufficient and appropriate financial resources for the acquisition of physical assets and to ensure access to suitable professional learning for teachers and teaching teams.

> *But it comes down to money. So ideally it would be good to redesign some more open spaces, storage and yeah, I think, you know, we, we are quite lucky here … but it's taken a long time to save that money to do that and applying for grants and seeking sourcing money from elsewhere (deputy principal, BPS).*

7.2.3.2.1 Physical resources

To foster the STEM learning, the case study schools made significant investments in physical resources, such as revamping a school farm and visitors centre, high-tech buildings/classrooms, and the acquisition of advanced technology devices. However, the case study schools also adopted a myriad of diverse technologies in support of the teaching and learning process of STEM, blending old technologies (textbooks) with new technologies (computers, tablets and robots).

7.2.3.2.2 Human resources and ongoing professional learning

Case study school principals committed to sourcing and resourcing people in their schools to develop staff capacity so they were able to advance their interest in and excitement about STEM learning, and to engage in and contribute to a strong learning culture within their school. Similarly, the principals each relied on a myriad of professionals (STEM teachers; Advanced Skills Teachers) to advance STEM learning and teaching, and much of the principals' focus was on developing the expertise of their staff.

> [The school has] *24 teachers and leaders. Farm operator. Two teacher assistants. We also have, at the moment, and earlier in the year we have an ASF volunteer student from Europe here ... So next year we have four new teachers coming into our space, two of them very young, one I took for a tour yesterday and her eyes were just she couldn't believe the environment. So I'm really excited to see what she will do with the environment (principal, HFPS).*

An ongoing commitment to the professional learning of their staff was characteristic of all case study school leaders, with schools focussing on harnessing and enhancing the capabilities of teachers in various aspects of their professional practice.

7.2.4 Principals' Knowledge and Experience

In all case study schools, the principals were pivotal to fostering the practice of STEM and, while their backgrounds haled from a diverse range of disciplines (history and legal studies, home economics and primary generalist), each of them was a long serving teacher (over a decade) and leader (that is, they had principal roles in previous schools) in the profession.

7.2.5 Principals' Personal Philosophy and Beliefs

The beliefs and philosophical orientations of case study school principals were reflected in their actions. Both school principals and their staff talked about various aspects of the principal's approach to leading the school including:

- Developing a learning culture, that is, the ability to learn, unlearn and relearn … *"once you do it properly and becomes part if you like the work processes"* (principal, CC).
- Taking a pragmatic approach to decision making to achieve immediate and long-term goals ... "*there was just something about him at the interview that I thought you are going to be one great maths teacher if I can give you the right set of preconditions"* (principal, CC).
- Empowering teachers to make decisions … *"empowering people to achieve the outcomes without necessarily giving them additional work to do and I think that's really important"* (teacher 2, CC).
- Resilience; being flexible, adaptable and bounce back after failure … "*you don't go anywhere unless you actually learn and for our kids in 21st century, that's an important message about resilience too because but they have to be resilient"* (principal, CC).
- Maintaining open, honest, and strategic communication ... *"I tag them in all sorts of Facebook posts that are around engaging our students in outdoor activities, of how purposeful it is, and how good for them it is"* (principal, HFPS).
- Commitment to accountability for themselves and their staff … *"we've asked the teachers rather than to have, just to have student workbooks on the desk to actually have a STEM activity so that children can talk to the parents about what STEM does. How it works and what, what the outcomes are"* (principal, BPS).
- Ensuring equitable opportunities for all students ... *"ensuring that we, first of all, are able to identify those students that may well be struggling is critical"* (principal, ASMS).

Case study school principals and teachers also referred to qualities that they considered essential to effective leadership of STEM in their schools, including:

- Being a risk taker … "*I'm quite prepared to take risks in whatever way as long as I know what the finance figures are"* (principal, CC).
- Being strategic … *"I'd been aware that really what I just needed to be able to do in a space like this is to support and to implement strategic approaches to improvement, both on the farm and the Visitor Centre, and the school"* (principal, HFPS).
- Being flexible … "*taught me to be flexible it's taught me to be adaptable it's taught me resilience in that you don't always get the things that you want"* (principal, CC).
- Striving to attain trustworthiness and respect throughout the school … *"there's a strong sense of trust and respect between students and teachers here … And pretty approachable. You know if you've got issues around whatever, it's a pretty open-door policy literally"* (teacher, ASMS).
- Being innovative … "*as a teacher I was always an innovator … always looking for what else can I do, how can I do this better, and always really willing to try new things. So I suppose I still, I could see, I still would have my teacher's hat on in terms of seeing what the possibilities were here"* (principal, HFPS).

7.2.6 School Organisation and Staffing

7.2.6.1 Distributive and team-based structures

The case study school leaders typically adopted a combination of flexible structures to organise the school and its staff, including both distributive and team-based structures. Both structures allowed decisions to be made collaboratively within teams that existed at various levels of the organisation and that were both vertical and horizontal.

> *So my two deputies, one runs the upper school, one runs the early childhood and so we'll have, we'll break staff meetings up into phases of learning and that gives them the opportunity to talk on more specific areas with teachers in their year groups (principal, BPS).*

The achievement of the case study school principals' vision for STEM was reliant on a strong team made up of a diverse, supportive, and collaborative individuals. In some cases (for example, HFPS), specific individuals were targeted to advance their STEM education vision (such as an Advanced Skills Teacher) and to work with staff to enable a coherent approach throughout the school.

> *Where we really have to with it we've been very fortunate we've got a very stable staff now … is both good and bad but we have staff who want to be here and we are pretty much on the same page and I think we have to also be brave enough to say if people aren't on the same page, is this the right place for them? (principal, CC).*

A common characteristic of the case study schools was the adoption of collaborative planning teams, which are formed at various levels across the school. For instance, grade level teacher teams planned daily teaching activities, moderated assessments, and shared ideas about their teaching practices, while leadership teams strategised long-term development projects.

Teachers working in teams to plan their work (such as grade teacher teams, interdisciplinary teams and STEM teacher teams) were provided with time and resources to collaborate. Principals aimed to empower their teachers; while they trusted them to achieve the planned outcomes, the teachers' engagement hinged upon their feeling valued and knowing that their ideas can be shared in an open and trusting environment.

Case study schools also employed a range of professionals to support the work of teachers; for example, agronomist, farm manager and visual designer. Each of these staff provided specialised services within or outside the classroom.

7.2.7 Pedagogical Approaches

Each case study school had a diverse student body in terms of background, culture, abilities, age and performance. Teachers were encouraged to adopt methods that fostered the diversity of their student population and enabled them to access appropriate learning experiences and to achieve useful learning outcomes.

Each case study school adopted a variety of flexible, interactive pedagogical approaches to STEM education, including inquiry-based learning, outdoor learning, problem, and project-based learning, drawing upon an integrated approach to STEM/interdisciplinary learning, and play-based learning.

Where possible approaches that drew from students' interest and were industry relevant and/or context specific (such as the HFPS farm environment, or adjacency to a university) are encouraged. The development of 21st century skills was seen to go hand-in-hand with STEM learning of this kind. Students were supported to develop their curiosity, creativity, independent thinking, collaborative skills, critical analysis and reflective practice.

To achieve this level of flexibility, teachers' roles were highly diversified. They tended to perform multiple student-centred pedagogical roles and were viewed as facilitators, learners, leaders, and mentors of other teachers, both within and beyond their own school.

> *I think allowing, being a facilitator in the classroom rather than a director. So rather than saying this is how you can do it and this is the outcome that you will get, posing questions to children. So changing the way that we work with children and facilitate that discussion, and posing the questions and helping guide them to find perhaps solutions, but not necessarily telling them always the solution (deputy principal, BPS).*

7.2.8 Working Within the Community: Engaging with Parents and Stakeholders

The community within which the schools sit were essential stakeholders of the schools' approaches to STEM learning and teaching, and pivotal to the success of their initiatives. Engaging Parents/Carers in STEM programmes, and to understand or accept that interdisciplinary approaches to STEM are valid, was sometimes a challenge. Case study school parents and others within the community were kept informed of the schools' vision and progress to achieving it through ongoing and targeted communication activities, including regular newsletters and contributions to social media.

> *… [our Advanced Skills Teacher] again has been fantastic in the communication and publication of the work that we are now doing, so there's a lot of Facebook posts going out, so parents see photos of us engaging in the farm, and that it is really specific to learning (principal, HFPS).*

For the two secondary case study schools, school alumni provided a very useful source of knowledge and inspiration for current students considering STEM as a career.

> *Working with alumni to get them involved in the school and potentially be mentors and work with us. Just maybe potentially to show students different career paths because many of them they want to be a doctor, and that's all they know. They don't know anything about podiatry, dentistry, physio, occupational therapist, audiologist, ophthalmologists. A whole range of things, different things they can do in the same kind of field and not necessarily as hard to get into potentially (deputy principal, ASMS).*

Wherever possible, case study schools sought opportunities to collaborate with other schools and institutions for ongoing professional learning, an approach that was regarded as a mutually beneficial way of achieving their goals for STEM education.

7.2.9 Current Challenges and Dilemmas

The challenges and dilemmas facing varied across schools, due to their context and circumstances. Shared concerns included:

- the ability to effectively engage parents and the community in their STEM strategies;
- the impact, perceived or otherwise, of the curriculum and assessment requirements; and
- the occasional resistance of some teachers to changing their practice.

More specifically, the challenges and dilemmas principals noted were:

- including parents in their plans for STEM education;

- attracting and sustaining an authentically engaged community supportive of STEM innovations;
- curriculum constraints to interdisciplinarity and integrated STEM/STEAM;
- working within narrow assessment processes and reporting expectations;
- resistance amongst some teachers to embrace new approaches and innovations;
- dealing with a transient school population and the variation in experiences of STEM;
- orientation of the students towards STEM learning; and
- anticipating and addressing multicultural dynamics, including pedagogical approaches perceived as challenging for some cultural practices and beliefs.

7.2.10 Plans for the Future

Despite each principal having experienced some hurdles to achieving their goal for STEM education, none of these issues were seen as unsurmountable; nor did they appear to impact the enthusiasm of the principals. Importantly, none of the case study school principals felt they had succeeded in achieving their goals for STEM in their schools. Each one highlighted their specific, strategic plan for advancing STEM education.

The principal of CC was not so concerned with the ways in which STEM learning was being undertaken in her school; rather, her future plans were to focus on improving the holistic development of her students. In particular, she wanted the students to develop their critical thinking skills through their learning of STEM.

The ASMS principal planned to strengthen the quality of integrated STEM education and interdisciplinary learning. She wanted to focus on improving the communication of the importance and relevance of integrating subjects authentically. While paying ongoing attention to motivating her teaching staff to teach in this way, the ASMS principal was keen to both monitor and evaluate the impact of these pedagogies on student engagement and learning.

> *So, we will celebrate those that work in that space. We will share not only what they're doing, but also the outcomes of what they're doing. We will review that to see how we can improve that and then we will look to spread it further in the following years. As a leader, you can't just go bang. It's all happening here. You've got to have people with you, otherwise you're not leading anyone (principal, ASMS).*

At HFPS, the principal wanted to continue to build upon the leadership of her AST to focus on strengthening their instructional model for teaching, with a particular focus on mathematics and English. The principal felt that there was also a need to work on both pedagogical expectations and being accountable in achieving set goals.

> *… for me, part of my leadership will be around expectation and accountability … so for the first couple of years it is, with [the AST] there's an expectation that they are participating in it, but other activities that's opt in and opt out really. But over time it will become part of their, I suppose the Hagley commitments of how we work (principal, HFPS).*

At BPS, the principal was keen to incorporate more digital technologies into teaching and learning in order to improve student outcomes, through empowering teachers to become leaders of STEM.

> *I've now put in a second team at the moment and with a focus not on STEM that other schools would be doing, but to focus on how to incorporate digital technologies into STEM more so … we've now got a new team of four teachers being trained up as leaders in digital technologies across schools. The school to set a new agenda for the school for the years ahead (principal, BPS).*

At the heart of this goal was his desire to focus on an integrated approach to delivering the curriculum, assisting teachers, and their learners, to identify authentic ways to link curriculum areas. He intended to achieve this through focussed and supportive professional learning and within and between school mentoring.

7.3 The System Case Study

The approach taken by the Western Australian Department of Education (WA DoE) to supporting innovative and effective leadership of school wide teaching and learning practice, and professional learning programmes in STEM education, was identified through the PASL Reference Group. The WA DoE system was selected as the System Case Study (WASCS) to provide 'what is possible?' insight into whole of system, whole of school, and principal-led STEM education.

7.3.1 The Research Approach

The case study was investigated by one of the PASL team, with interviews conducted across a breadth of participants who had particular roles in leading and conducting the WASC approach to leadership in STEM education. Five participants were interviewed: four were senior managers for the WA Department of Education and the fifth was a representative from the Department of Jobs, Tourism, Science and Innovation.

Interviews focussed on STEM professional learning programmes, STEM and its learning and teaching, school organisation, professional learning, systematic support, relevant policies, the STEM resources available, teaching approaches, and beliefs about STEM (from SSHREC ethics). Some demographic and background data (such as their name, educational background, length of time in their current role) were also collected of the participants during the interviews.

7.3.2 System Case Overview

The DoE WA views STEM education as an integrated, innovative and inter-disciplinary approach to learning. Students are guided by capable school principals, leadership teams and teachers to engage creatively with real-world problems, applying their understanding of the key areas of science, technology, engineering, and mathematics. As a result, students build deep knowledge of the STEM disciplines and actively develop:

- their critical thinking, problem-solving, and collaborative capacities;
- their interpersonal, teamwork and communication skills; and
- their ability to creatively use digital technologies, to effectively function in a changing world.

POSITIVE AND/OR UNIQUE FEATURES THE WA DOE

- Cross-sectoral involvement for the development of a shared vision of STEM in Western Australia.
- Sustained investments in STEM education policy, practice, and human and educational resources development.
- Setting up communities of practice in schools to encourage school autonomy in addressing their professional learning needs and sharing exemplary STEM practices with partner schools.
- Promotion of well-aligned development of higher-order skills, digital skills, and STEM discipline skills.
- Participatory and outcome-based monitoring and evaluation to inform the STEM policy, initiatives and practice.
- Commitment to ensure equal opportunities in STEM access in WA schools.

7.3.3 Developing capacity in STEM

The DoE WA has invested $3.3 million in professional learning and mentoring initiatives for the development of STEM education across WA schools. The aim is to move learning and teaching from a focus on only building students' content knowledge to also developing the 21st C skills that will be needed for future jobs[15] and to inspire more students to pursue STEM learning and STEM-based careers.

> *… for us, it's about the development of the STEM skills, so it becomes part of the way you think and the way you operate in terms of having an evidence base for your approaches. Having a systematic and reasonable approach to decision-making. That you are creative in that as well, but that it's not just innovation for the sake of innovation of doing something different, it's actually about a process that leads you through how you operate and how you think in a way that takes you trying something new and testing, iterating and evolving, and all the skills that go with that (CSP-1).*

Key features of and processes underpinning DoE WA capacity building initiatives are outlined following.

7.3.3.1 A whole school approach to professional learning

The system has taken a whole-school approach to professional learning aimed at enhancing capacity for STEM teaching and learning. School principals participate in STEM PL, in addition to their leadership teams and teachers; they identify their own learning priorities and ensure that the PL is closely aligned with school contexts.

[15] https://www.education.wa.edu.au/stem

… a lot of our remotes do STEM on Country. So, they'll go out and they'll be doing maybe the science and the maths together on Country; some schools … have that extra session and they timetable it like a real life problem-solving, project-based learning; different schools do explicit teaching and know they like blocks of maths at this time, and that's okay too [as long as] we're talking all of this problem-solving, critical-thinking, creativity and innovation; whereas our big high schools with great experienced staff can do all of that and they've got some really great STEM practitioners that do the science and the maths together (CS leader 2_1).

7.3.3.2 STEM innovation partnerships

In 2016, the DoE WA identified five system challenges to quality STEM education in schools:

1. How STEM education could be best undertaken in classrooms.
2. Principals' and teachers' capacity building to deliver STEM education effectively.
3. Teaching and learning practices that might enhance students' engagement in STEM.
4. Forms of assessment that would measure the effectiveness of STEM initiatives.
5. The role of partnerships with community groups and industry.

To explore these five challenges, DoE WA began the first phase of Innovation Partnerships[16] in 2016. In the first round of phase one, 27 schools with expertise in STEM, their principals, leadership teams and teachers, collaborated to design STEM learning experiences with and for their students over a two-year period. The participants learned from and with each other and were supported through a series of workshops designed to delineate their vision for STEM education and to implement their context-specific STEM plans in their schools.

The success of this partnership approach, in terms of participant enthusiasm and progress towards useful outcomes, was such that the DoE WA invited a further 34 schools to join the Innovation Partnership in 2017 and, in 2018, the DoE WA extended the partnership focus to include digital technologies, provide support for Aboriginal students, and foster engagement and retention of secondary school students.

7.3.3.3 Ethnographic research: Identifying students' learning needs

Principals were supported to undertake ethnographic research in their schools during their participation in the Innovation Partnerships. The aim was to consolidate their thinking about STEM and to identify their target learning areas. They were encouraged to gather data from principals, leadership teams, teachers, students and parents and, if appropriate, from relevant industry partners.

STEM looked very different in each of the contexts and they were equal in terms of their outcome and their impact on the children, but actually, they were very different and it looked very different in different environments … some schools found that their challenge was really to improve teacher capacity whereas other schools found that they needed the … physical environment sort of thing, and if it was somewhere where they could be creative and allow that collaboration and be interesting and innovative, some schools actually stepped outside the walls and they created spaces outside because they wanted their students connecting with, especially some of our country schools (CS Participant 3).

[16] https://www.innovationunit.org/projects/stem-innovation-partnerships/

7.3.3.4 *Design-led workshops*

Workshops were conducted to help teachers in Innovation Partnership schools build their knowledge of STEM teaching and learning, and incorporate their students' feedback into the iterative cycle of STEM improvement. The contextualised approach meant that STEM learning and teaching looked very different in different Innovation Partnership schools. All schools engaged in the proactive evaluation of their STEM innovations, iteratively improving their work throughout their involvement in the partnership.

7.3.3.5 *STEM enterprise and innovation partnership schools*

In the second phase of the Innovation Partnership scheme, schools that had participated in the first phase (known as 'pioneer schools') were identified as STEM Enterprise Schools[17]. These schools provided mentoring for schools participating in subsequent rounds of the Innovation Partnership programme, effectively cascading the programme.

Second phase Innovation Partnership schools trialled in their contexts some of the innovation strategies and tools that had been developed by the pioneer schools. They then provided critical feedback on the relevance and effectiveness of the innovation practices in their own schools. Through this participatory, peer support system, the DoE WA was able to influence the development of quality STEM pedagogy throughout WA schools, with the following three benefits:

1. achieving a broad reach across many WA schools;
2. effective dissemination of STEM best practice throughout WA schools; and
3. improved STEM policy, strategy, and pedagogy in WA schools through intensive iterations, monitoring, and evaluation of practice.

7.3.3.6 *Evaluating outcomes*

Evaluation data indicate:

- increased student participation, capability, and aspirations in relation to STEM;
- improved teacher competence and capability in STEM; and
- a growth in the use of research in their school.

Many schools also reported overall positive outcomes relating to the integration of technologies into their classroom practices, the development of new curricular content, improvements in pedagogical approaches in STEM, growth in monitoring and assessment resources, and new ways to engage parents in raising awareness or the importance of STEM.

7.3.4 Learning-Enriched STEM Culture in WA Schools.

The DoE WA has created rich STEM cultures in its schools. The STEM culture is characterised by nine key factors, discussed following.

[17] See http://det.wa.edu.au/curriculumsupport/detcms/school-support-programs/curriculum-support/news-items/state-stem-strategy/stem-and-innovation-opportunities-for-schools-in-2019.en

7.3.4.1 *Sustainable professional learning communities*

The establishment of principal-led communities of practice (CoP) in schools through which STEM learning was embraced by the school principal, leadership team, and teachers, resulted in students being the ultimate beneficiaries. As leaders of curriculum and the professional culture within schools, the DoE WA considered the role of school principals to be vital to the success of the CoPs.

> *I suppose from real leadership perspective school leaders have been involved in that professional learning. And we find that with most projects we have if there's leaders that are involved, there tends to be a greater uptake within a school. And I guess that's it, you know the principals are the key to creating that school culture, I suppose, or environment where teachers are willing to change practice. So, where we've had them involved in…participating in that STEM shift … was quite good (CS Participant 3).*

The culture was experienced by teachers as learning-enriched, and they willingly participated in initiatives aimed at changing pedagogical practices. Teacher attrition can disrupt the progress of STEM innovation, but this disruption can be mitigated against through teachers participating in PL in teams. Similarly, the involvement of a critical mass of teachers and school leaders from each school contributed to its sustainability.

7.3.4.2 *DoE WA Leadership Institute*

The DoE WA Leadership Institute mentored principals to lead their teams and manage school environments as learning and innovation hubs. PL was available to principals in face-to-face, online, and through self-directed modalities; its design, content and delivery of the principal PL followed evidence-based approaches underpinned by adult learning principles.

7.3.4.3 *State-wide showcase of good practice*

At the end of their participation, schools showcased their practice in STEM, as well as the challenges they experienced and how they addressed them. Schools attending these showcase events were encouraged to adopt any of the practices shared and to customise them to suit their school contexts. Schools that were keen to experiment with STEM practices in their schools were assisted with resources to support innovative STEM lessons and pedagogical approaches.

7.3.4.4 *Active involvement of informal community groups*

The DoE WA involved community groups in their STEM interventions and encouraged families and their friends to undertake STEM projects in their homes, thereby further strengthening STEM culture in schools. It recognised that many parents were interested in supporting their children's STEM learning, but lacked the necessary STEM knowledge or understanding of how they might best participate in their child's education. The most recent showcase organised by the DoE WA focussed on regional technology attracted nearly 6,000 attendees (children and their families). The WA DoE also leveraged the importance of sophisticated technologies to the state's thriving mining industry through partnering with industry bodies.

7.3.4.5 *Strong education-industry links*

The DoE WA maintains strong connections with industry and connects STEM experts with teachers and students in schools. These collaborations empower teachers and enrich classroom resources, and students have been able to participate in site visits and work experience, thereby providing them with industry-supported pathways to STEM careers. DoE WA is working to identify and prioritise the involvement of schools that would benefit most from

enhanced industry connections, ensuring that the benefits extend to schools in low socioeconomic and regional areas.

> *So, this idea that industry can really bring STEM alive in the class and inspire young people to consider those STEM careers. So that was a strong element there and I think that's been a big part of the programme (CS Participant 5).*

7.3.5 DoE WA Approach to STEM Pedagogy, Curriculum, Assessment and Equity

7.3.5.1 Inquiry-based pedagogy

WA DoE encourages schools to adopt inquiry-based STEM learning. To support such pedagogies, the DoE WA has developed teaching and learning resources for STEM[18] teachers that support them in providing stimulating, interactive and challenging learning experiences for their students, and support them to develop STEM capabilities needed for employment.

7.3.5.2 Curriculum

The DoE WA has established curricular guidelines around teaching, learning and assessment and how they are inter-related. Interdisciplinary approaches to STEM teaching and the application of discipline knowledge to complex, real-world applications are encouraged so students understand the ways different subjects are connected.

7.3.5.3 Assessment

Formative assessment is central to their strategic conversations with school principals and leadership teams about reforming STEM education. Through the STEM Enterprise programme, the DoE WA has supported participants to gather evidence of students' progress in conceptual understanding of STEM concepts and their development of STEM skills, with a view to using this information in its pedagogical decision making.

> *It all comes down to really good pedagogy in that we don't just assess for that summative assessment, that we're assessing all the time to inform teaching and learning. I suppose that's good pedagogy and a lot of our teachers have been doing that all the time but there does need to be a genuine connection between those things, viewed as a cycle and that assessment doesn't need to be sitting in a corner by yourself doing a test that you can, you know you can, it's where people are at in different ways and then use that to inform the teaching and learning that's going on in a classroom (CS Participant 4).*

7.3.5.4 Equity

A focus for the DoE WA is ensuring that girls, learners from low socioeconomic backgrounds, Aboriginal learners and culturally and linguistically diverse students in WA schools are provided with equitable access to STEM initiatives. It has developed a number of initiatives to support equity, including:

- raising awareness in the STEM Enterprise Schools programme;

[18] https://www.education.wa.edu.au/resources/stem-learning-project

- supporting schools to undertake research into students who are disengaged or under-achieving groups in STEM; and
- assisting schools not meeting the criteria to be a part of the STEM Innovation Partnership programme, to address equity issues in STEM.

Other innovative approaches have been taken to increase the participation of Aboriginal students in STEM (for example, Aboriginal Education STEM Program[19]; Premier's Science Awards[20] an Aboriginal STEM Student category) and STEM Camps for girls and Online STEM Enrichment Programs have been created for non-metropolitan and disadvantaged communities. The DoE WA also plans to increase its resourcing of teachers and learners of STEM in regional areas, to both enhance STEM education and to assist students to make informed study choices.

Finally, the DoE WA plans to increase its focus on lower socioeconomic schools to ensure they:

- are staffed by STEM-qualified teachers;
- encourage students to take STEM subjects at higher levels;
- increase the number of girls studying STEM; and
- ensure all students have access to optimal STEM experiences and opportunities.

7.3.6 Challenges, Priorities and Directions

Sustained commitment has been a hallmark of the DoE WA STEM initiatives and is crucial to the success achieved to date. The DoE WA has identified six areas as foci for ongoing or future initiatives:

1. Mentoring school leadership in medium to low socioeconomic schools to facilitate learning and innovation cultures in their schools to positively influence student learning.
2. Encouraging a shift to inquiry-based pedagogy through a STEM-supportive curriculum to ensure students' learning is purposeful, engaging and future-focused.
3. Strengthening partnerships between schools and industry to benefit teachers and students by engaging them with STEM ways of thinking.
4. Ensuring sustained professional development opportunities and provision of resources for research, and pedagogical innovation in schools particularly in schools serving medium to low socioeconomic communities.
5. Creating of equitable learning environments and opportunities for all students.
6. Enhancing support for students' aspirations for STEM careers through assisting principals, leadership teams and teachers to better guide students' thinking about their futures and possible career paths.

[19] https://www.scitech.org.au/incursion/aboriginal-education-program-student-workshops/

[20] https://www.wa.gov.au/organisation/department-of-jobs-tourism-science-and-innovation/premiers-science-awards

7.4 Case studies cross-case analysis and systems case: Concluding comments

The cross-case analysis of the four case study schools from across Australia demonstrates there is no single way to achieve exemplary practice in STEM teaching and learning. Each of these schools is varied in its approach, implementing both integrated and subject-based STEM approaches. These approaches are undertaken within the classroom during school hours, and outside the classroom and school hours, through extra-curricular activities.

All case study school leaders displayed innovative, effective, and often entrepreneurial leadership of the school-wide teaching and learning practice of STEM education in their schools. It is clear from their interview responses that STEM requires investment in both physical and human resources. Leaders' knowledge of STEM discipline and integrated knowledge and practices helped principals recognise that to advance STEM teaching capacity within their school, recruiting and then supporting their human resource through the provision of ongoing professional learning is of pivotal importance. Principals were able to achieve this capacity by taking advantage of every opportunity to gain financial support to source and resource motivated and skilled staff.

The STEM tools that the principals invested in varied in relation to their vision for STEM (such as access to STEM-rich curriculum for girls), context (STEM in agriculture) and the needs of the students (access to technology). Pivotal to the approaches each case study school implemented STEM was the context within which it located. For example, HFPS school is perfectly situated to ensure that its STEM approach is grounded within the farming environment and agricultural science, while the close proximity of ASMS to Flinders University presents quite different opportunities to engage with university staff and industry contacts. Further, case study schools were located in communities that interacted closely with each school, including those with a deep sense of investment in the school and its operations, a culturally diverse parent/carers body and diversity of socioeconomic backgrounds.

A common characteristic of all principals within the case study school was the disposition towards generating a positive STEM culture within their schools. Access to opportunities to engage in STEM learning (through a whole-of-school interdisciplinary approach) that are relevant and authentic (as with, STEM on the farm), customised to student needs (such as extracurricular engagement in STEM) and the enhancement of teacher capability (student-led technological expertise development) was key to their strategic approach.

Distributed leadership and mentoring of teachers through the establishment of appropriate teams was pivotal to capacity building. Both leadership and teaching teams were established in order to enact the principal's vision of STEM. Teacher practice was supported through the establishment of appropriate teams to collaboratively develop resources, share practice and mentor others. Each principal was highly visible throughout the school; 'walking the talk' and listening to students and staff as they implemented change.

Case study school principals were at different stages in their journey towards achieving their vision of STEM education in their schools. At the time of this Report, HFPS was two years into the implementation of their strategic and well-supported approach to creating a vision for STEM education and organisational culture, while ASMS had been operating in a STEM-rich space for 16 years with an established mission of preparing students for university, particularly in the field of mathematics. However, each case study school principal maintained a critical stance to evaluating how they were progressing towards their goals, and were either actively gathering, analysing and acting upon data or designing an approach to generating evidence. While some synergies between case study school can be identified, it is not possible nor desirable to conclude there is one way to conceive of and implement exemplary practice in STEM teaching and learning.

From a systems perspective, the WA DoE fully committed to spreading state of the art STEM learning innovations in its schools. To enhance meaningful student participation and engagement in the learning process, WACSC found that school curriculum must connect students with their real-world and the prospects in which they are interested. In this regard, multi-sectoral involvement (DoE, whole-school, community and industry) has helped in the past, and strengthening this involvement in the light of past experiences will ensure sustainable growth in this sector.

The WACSC analysis found that the principal-led STEM innovation initiatives in schools have generated good results; more work in this direction (by shaping these initiatives as future-focused and equitable in their availability and participation) will help schools to adapt to the changes that arise from the rapidly changing, interconnected world.

8 Monitoring and evaluating PASL process and outcomes

8.1 Summary of the evaluation

The PASL project was a national project, which involved team members from:

- six states;
- government;
- Independent and Catholic education systems;
- a reference group drawing on national expertise in STEM education; with
- regular oversight from the DESE professional officers.

It was a complex project managed over three years.

The eight aspects of implementation adapted (Durlack & DuPre, 2008) for the evaluation of the PASL project were:

1. Integrity: the extent to which the intervention adheres to the proposed programme.
2. Coherence: the extent of collaboration between key stakeholders to achieve project goals.
3. Quantum: the amount and scope of the. professional learning delivered.
4. Quality: the relevance, currency and accessibility of the professional learning.
5. Engagement: the extent to which participants valued and acted upon the professional learning.
6. Innovation: the unique nature of the project and the degree to which it could be differentiated from other programmes.
7. Reach: the extent to which the participants and exemplar case studies are representative of the target audience.
8. Adaptation: the ability of the project team to respond to feedback and adapt to changing conditions.

8.2 Analysis of the evaluation reports

A summary of the key findings in relation to the eight aspects evaluated is provided in Table 17.

Table 17: Key findings in relation to the eight evaluated aspects

ASPECT EVALUATED	KEY FINDINGS
1. INTEGRITY	• The research design was elegant and reflected a 'gold standard' approach of comparing experimental with 'business as usual' school clusters. • It was sensitive to a number of challenges, such as delays related to ethics approval, which impacted recruitment and the facilitation of similar clusters. • The members of the reference group were well informed and offered a 'sounding board' for the planning and implementation of the project. • The opportunity for educators from different state departments, professional associations, and universities to come together as members of the reference group was considered a valuable and unique opportunity. • The principals had the benefit of a PL module delivered either face-to-face or online by an experienced member of the project team, access to online learning resources, and the opportunity to engage with other principals regarding leadership and STEM learning.
2. COHERENCE	• The collective team was interdisciplinary with a broad skill set that included a wide diversity of experience and expertise in leadership, STEM disciplines, teaching and learning, professional development and delivery, evaluation, community outreach and research. • The team was cohesive, and the diversity was valued as a strength. • The team members expressed a high level of confidence to undertake and successfully complete the project. • The presidents of the principals' associations understood their role as a professional conduit between the team and state-based organisations. • For the members of the reference group, the experience of being able to contribute experience and expertise to benefit the project varied.

ASPECT EVALUATED	KEY FINDINGS
3. QUANTUM	• Three professional learning programmes (13 modules) were developed by the project team, delivered, and revised with feedback from participating principals. • Five case studies of good practice were developed. • A case study focused on good practice of STEM education in indigenous communities was not possible given access delays due to COVID-19 and then staff changes within the community. • All of the case studies, as well as the PL modules including facilitator notes, will be distributed on the website hosted by ASPA. • Some principals expressed the desire for a follow-up session to report on progress, share experience and seek feedback, beyond the life of the project. • Too few schools were recruited to the project to allow clusters of similar schools. • Not all principals wanted a mentor or critical friend, but those involved benefited from the networking opportunity PASL presented.
4. QUALITY	• The principals appreciated the quality of the professional learning and the opportunity for engagement with the presenters. • Most principals agreed it was too early to determine the full impact of the project indicating that real cultural change may take months, or even years, to evidence. • The processes of obtaining copyright for the necessary publication under Creative Commons has been challenging for the project team. A key learning for all team members and DESE is the extent to which a Creative Commons licence can impact third party materials, and in regards to potential intellectual property concerns.
5. ENGAGEMENT	• The principals were required to: - develop a plan to promote STEM learning in their school and inspire the teachers, student, and wider school community to engage with, and support, change initiatives; and - participate in research and evaluation interviews, encourage teachers to participate in surveys and interviews, and facilitate the collection of survey data from students. • The challenge of collecting data from staff and students was considered the main disruption, but most principals agreed that the current and potential benefits outweighed any short-term inconvenience. • They expressed mixed views about the concept of a 'school cluster' as a positive component of the professional learning experience. • Few of the participants were allocated a critical friend and, for some, this was a lost opportunity. • In 2020, COVID-19 created further challenges and the opportunity to focus on STEM initiatives was diminished. • Some principals withdrew from the project and others, who continued to participate, had less time than anticipated to commit to follow-up interviews and data collection.

ASPECT EVALUATED	KEY FINDINGS
6. INNOVATION	• The project emphasised the key role of principals in organisational change and their leadership development was at the forefront of the project. • Leadership cannot be delegated if initiatives are to be perceived as a priority for the principal. • By enhancing the knowledge and skills of principals, they will become more confident leaders and better able to undertake the task of organisational change to facilitate STEM teaching and learning. • The reference group members noted several successful strategies implemented in the PASL project that might be adopted in future work, including: - cross-sectoral collaboration, - the evaluation process, - the key involvement of the principal's associations, - the quality of the documentation, and - the challenge of managing a complex national project.
7. REACH	• Principals were recruited from all six states participating in the project, and government, Independent, Catholic, primary, secondary, and K-12 schools were included in the trial of the PL modules. • The ability of the presidents of the principals' associations to assist with the recruitment of principals and the identification of potential school clusters and critical friends to the principals undertaking professional learning was compromised by time pressures on the presidents, and the sense that selecting potential critical friends created a conflict of interest for their professional role. • COVID-19 and the delays in ethical approval were contributing factors to the reduced level of recruitment of principals and the identification of critical friends.
8. ADAPTATION	• The team was forced to quickly adapt the delivery of the PL modules due to COVID-19 restrictions. As a result, professional learning materials, presentations and group discussions were delivered on-line. • Monthly meetings of the project team and the use of CloudStor to share data were introduced to improve team communication. • A case study about a system wide approach to STEM education was developed at the recommendation of a member of the reference group. • The research design and data collection strategies were modified to accommodate COVID-19 restrictions.

8.3 Summary

The project team was dispersed across the country and worked in relative isolation on the PASL project, apart from email contact and monthly online meetings. Educational leaders experience multiple pressures that can be difficult to manage; rarely is there an opportunity to authentically debrief with someone who is able to balance affirmation and challenge. The telephone interviews were designed to collect qualitative data about the project implementation. Nevertheless, there was the opportunity for the external evaluator to provide support, encouragement, information and insights. Despite being a relatively brief encounter, there was the possibility of a small change and positive shift in perspective. Although never intended as a therapeutic intervention, the telephone interviews with team members allowed the sharing of some of the aspects and techniques associated with single session interventions (Dryden, 2018) and contributed to the cohesion of the team. One comment from a team member, following the telephone interview when they responded by email to validate the discussion summary, affirms the importance of the holistic evaluation approach that PASL undertook:

> *Thanks again for the chance to reflect on the project and my involvement in it. I've added a comment on the evaluation aspect of PASL which I haven't seen done this way before and has been a definite positive for the project.*

Similarly, interviews with the principals were helpful beyond the collection of participant data for research purposes. The evaluation team recognised the importance of developing rapport and trust with the principals. The semi-structured questions, with prompts, were valuable for encouraging narratives, as well as eliciting specific information. Many of the interviews were undertaken during a stressful time of school closures, the move to online learning, high parental and teacher anxiety and unprecedented expectations for principals to show leadership across the wider community. The interviews offered person-centred engagement and recognition of the challenges faced by principals (Prior, Mather, Ford, Bywaters & Campbell, 2020).

Although the concept of a critical friend was not successfully implemented for the participating principals, it was integrated in the implementation of the project in several ways:

- The external evaluator acted as a trusted person who asked provocative questions, provided critique and took time to fully understand the context of the project and desired outcomes (Loughran & Brubaker, 2015). This reflects the "three characteristics central to an effective critical friendship: vulnerability, reflection and scepticism" (Petroelje Stolle, Frambaugh-Kritzer, Freese & Persson. 2019, p. 23).
- All three characteristics were evident in the willingness of the team to participate in the interviews, review and discuss the evaluation reports and confront the sharply divergent perspectives of the DESE professional officers.
- Hall, Freeman and Colomer (2020) describe a formative evaluation of a professional development school and identified their failure to integrate themselves as critical friends at the onset and provide critical midcourse feedback as a missed educative opportunity.

The presidents of the National Principals' Associations brought a unique perspective to the team and helped to reframe situations from a deep understanding of the work context for principals. Teachers may be locked into the 'daily rigours of teaching' and find it difficult to adapt to new practices, whereas academics aspire to an ideal without due attention to the pragmatic limitations (Sanzo, Myran & Caggiano, 2015). Within the project team, the presidents of the Principals Associations acted as critical friends and helped to bridge vision and reality.

Importantly, the external evaluation has provided two important outcomes. First, it presented timely and important data for the PASL as it engaged in the project over three years, enabling the Directors to modify its rollout and/or pivot as required.

Second, the approach taken (see Table 17) and the evaluation template used would be valuable for other future project teams implementing national projects such as PASL, which seek to evaluate the effectiveness and efficacy of their work in real time.

9 Recommendations and Summary

9.1 Introduction

This chapter concludes the PASL report through a synthesis of outcomes presented in the preceding chapters, followed by a discussion of key learning and implications of the project, particularly in relation to:

- the importance of systemic investment in STEM capability development;
- the potential influence of the STEM Capability Sets on envisioning school leadership of STEM; and
- the ways in which research of this nature can inform practice and identify change.

Finally, Chapter 9 provides recommendations that have emerged from the research conducted in the project to achieve a whole of school culture of STEM. The chapter is concluding by a summary of how the PASL Project has impacted principals' understanding of the requirements for implementing a vision for STEM education.

9.2 Specific outcomes

The PASL project has achieved the goals of the three Work Streams identified in the PASL project brief (the outcomes are summarised following):

Work Stream 1: Research to inform the development of professional learning modules and practices leading to principal STEM leadership capabilities.

Work Stream 2: Development of professional learning modules/resources and research into their impacts.

Work Stream 3: Process monitoring and evaluation.

The research undertaken throughout the life of the project has assisted in the production of quality materials, endorsed by principals who engaged with these materials during the PASL PL.

In addition, PASL generated large data sets related to principals' understanding of STEM education and the importance of their role as leaders. This research was underpinned by an evidence-based framework for interpreting STEM capability (STEM Capability Sets) of principals, teachers and students. The analysis of these understandings has been reported here and will form the basis of future scholarly articles.

The extent to which the goals of the three Work Streams have been achieved is summarised, followed by a synthesis of the implications of the research outcomes for future projects supporting principals' professional learning. These implications are discussed in relation to the 19 recommendations that emerged from the project (see Section 9.3).

9.2.1 Documented Best-Practice and Expand Evidence-Based Approaches to STEM Leadership Approaches

PASL has provided a systematic review of recent Australian and international literature related to education in STEM and the role of principals, in two forms:

1. a high-level academic journal article, the audience of which is researchers in the field (under review); and
2. a journal article written with school principals as the audience, published in *Australian Educational Leader* (Likourezos, et al., 2020).

Both articles provide educational practitioners and policy makers with information and analysis of STEM education and its leadership in schools, and a discussion of the implications of research for the role of principals in delivering positive outcomes in STEM education.

The desktop audit conducted in 2018 (and enhanced in 2020) provides school principals, STEM teachers and educational researchers with an audit of all recent and current STEM education initiatives and resources in Australia. An analysis of the focus of these initiatives has been undertaken and gaps identified. The audit is available on the PASL website (devised for user interaction) to provides links to initiatives of interest.

Research undertaken into four case study schools provide evidence of exemplary leadership and STEM education practice in Australian schools. The analysis identifies synergies and points of difference in their contexts, leadership practices, strategies and journeys towards STEM educational excellence, for the consideration of principals and interested others.

9.2.2 Construction of Evidenced-Based High Quality and Accessible Resources

The three PL Programmes and associated resources developed collaboratively with principals and school leadership teams PL are accessible at the Australian Secondary Principals' Association (ASPA) website (commencing 2022). These programmes were developed rigorously and they drew from:

- the findings of Work Stream 1;
- aspects of the existing Principals as Literacy Leaders programme PL (PALL); and
- the expertise of STEM discipline and STEM education colleagues.

Each programme was designed as resource undertaken in isolation, or in a suite of programmes to be undertaken in a sequence, as a coherent PL programme. Principals can engage with the modules via different modes of delivery: face-to-face, online, and/or blended modes and in collaboration with other principals and/or their STEM leadership team. Each of the modules was developed by one or more of the PASL project team, based on their expertise and experience in STEM education and leadership. Principals who participate in the PL both engaged constructively with the materials, and enabled the PL facilitators to determine which learning materials and activities were (and were not) effective, by providing feedback.

9.2.3 Evaluation of the Impact of the Resources and the Project Processes.

The external and independent monitoring and evaluation of conduct of the PASL research project provided the project directors, research team and DESE personnel with insightful feedback that could be acted on in real time. Principals' feedback about the quality of the professional learning, and the opportunity for engagement with the presenters, contributed to both a change in the modules in real time, and modifications to the ways in which they were delivered to participant principals.

The outcomes of Work Stream 3 provided valuable information about the conduct of such national projects for

future researchers. While data generation (from principals, staff and students) is essential to research of this kind, and it was considered by principals as potentially disruptive, current and potential benefits outweighed this inconvenience. Similarly, while the research design was appreciated by principals as innovative and useful, the construction of clusters did not always achieve PASL intended goals. Also, although PASL valued critical friends as a key contributor to principal learnings, the implemented model did not prove successful. This outcome directly informed the selection of the fifth case study (see Section 7.3), which outlines a successful, 'whole of system' approach to the mentoring of schools.

This evaluation process also demonstrated the importance of induction processes for new members coming into project teams, particularly those who were not around when the project was conceptualised or commenced. Vital to the project's success was:

- constant communication between team members;
- ensuring team cohesiveness through face-to- face meetings and
- regular online team meetings.

Ensuring that all stakeholders share a common and ongoing understanding of the project's purpose and intention was a key learning outcome for the project directors. Finally, as PASL was created to support the learning of principals, the inclusion of the presidents of the National Principals' Associations as team members was essential. Their contributions helped project directors to reframe situations from a deep understanding of the work context for principals.

9.3 Implications

9.3.1 Recommendations for STEM Education

The PASL project has resulted in 19 recommendations derived holistically from the combined survey, interview, and case study data gathered as part of the PASL project. These 19 recommendations are presented in five key groupings:

9.3.1.1 System Focus

School principals practise their leadership of STEM in their schools within a larger jurisdictional, state and federal context. PASL research indicated that their ability to influence and achieve their innovative vision for STEM education can be limited by these broader contextual issues. Specifically, sustained funding is important for the resourcing (physical and human) of STEM education and the way it is distributed equitably to all schools in need, the potential and reality of the Australian curriculum acting as an impediment to integrated STEM, and the importance of rigorous cross-sectorial collaboration in support of the professional learning of principals. There are five aspects which relate to system responsibilities:

1. Sustained funding is required for science and innovation, infrastructure, and equipment, and for building the capabilities of teachers to adopt appropriate pedagogical practices. Despite multiple STEM-related projects and substantial total funding, the reach of projects such as PASL (which upon its conclusion requires voluntary engagement of individuals) is necessarily limited. The impacts of quality resources produced would be enhanced by facilitated roll-out and active dissemination.

2. More attention needs to be directed to schools from medium to low socioeconomic areas and disadvantaged communities, to provide principals with appropriate mentoring and access to resources and initiatives for the creation of equitable learning environments and an innovation culture.

3. The extent to which the curriculum is conducive to, or limiting of, STEM teaching and is influential towards the implementation of inquiry-based pedagogies that ensure students' learning is purposeful, interesting, and future-focused, requires further investigation.

4. For optimal success, national projects of this kind should include (as PASL did):
   - cross-sectoral collaboration,
   - an holistic formative as well as summative process evaluation,
   - the involvement of the principals' associations,
   - the development of quality documentation, and
   - acknowledgement of the real challenges of managing the complexities.

5. Rigorous longitudinal research tracking the impacts of projects, including at the student level, is needed to strengthen the evidence base about effective STEM teaching, learning, leadership and enhancement.

9.3.1.2 Community engagement

The engagement and commitment of community stakeholders in the STEM vision of schools was identified as being key to its success. This level of engagement requires both visionary and entrepreneurial principals who are required to develop effective school-community-industry partnerships, while also balancing the demands of managing the school. Principals rarely come to the leadership position with a complete set of skills of this kind; hence, they are required to develop them 'on the job'. Systemic support of their professional learning to ensure the development of the capabilities summarised in the STEM Capability Set is essential to exemplary STEM leadership.

6. Where possible an emphasis on the school-community-industry partnership needs to be developed and presented as a regular feature of the curriculum, enabling a bi-directional flow of STEM understanding between the industry and schools.

7. More support is required to assist principals to balance the demands of their school communities, and STEM education, and educational system and curriculum requirements, and to be able to communicate their STEM strategies effectively to their school communities.

9.3.1.3 Professional learning

PASL was designed to create research-led professional learning resources, trialled and evaluated with school principals. Hence, the importance of five particular aspects of professional learning, guided by the research outcomes summarised in this report, emerge as key recommendations of PASL.

8. Further investigation should be undertaken of the connections among teachers' STEM backgrounds, their beliefs and teaching practice, and elements of school climate and culture, and the resulting impacts on students as a basis of PL that is better targeted for teachers of different STEM subjects or integrated STEM.

9. The focus of PL requires attention to ensure that it assists principals and teachers to increase the academic challenge of STEM learning, focus on developing students' conceptual understanding and supports them to strengthen students' curiosity about STEM.

10. Professional learning programmes for principals would benefit from a focus on the use of data in determining future strategic directions, and ways in which these decisions are communicated to teachers and the broader school community.

11. Professional learning is needed that is aimed at strengthening teachers' knowledge in STEM disciplines and, hence, their self-efficacy, interest, and enthusiasm for teaching STEM subjects.

12. Principals and STEM leaders would benefit from a greater understanding of the role of STEM tools (resources) in achieving the broader goals of STEM education, such as problem-solving and critical thinking.

9.3.1.4 Individual STEM capabilities

The STEM Capability Sets comprised a key framework that underpinned the design of PASL PL, the analysis of the data generated from the project and for principals to use to evaluate their own capabilities and those of their staff and students within their school. By using the framework to analyse principal data, clear gaps in principals' STEM capability became evident. These gaps should form the basis of future principal PL and research related to STEM capability, and these have four aspects.

13. The STEM Capability Sets (introduced in Chapter 3) have been identified through this project as an effective framework for working with principals and STEM leaders to assist them to understand how to create a STEM-capable school. Further research is recommended with the aim of further validating the Capability Sets, determining how they might be used for professional learning purposes and for evaluating STEM capability at the levels of principals, teachers, student, and school communities.

14. The degree to which principals require STEM discipline-specific and technical knowledge capability, and the precise nature of that knowledge, to be effective in their various roles as decision makers in developing a positive STEM culture in their schools, requires further research.

15. Greater attention should be paid to:
    - the development of positive dispositions towards STEM among principals, teachers, students, and school communities;
    - building parental awareness of the importance of STEM learning as relevant for all; and
    - acknowledging its various demands in principals' professional learning programmes.

16. Principals, as well as their STEM leadership teams, should be participants in STEM PL and initiatives in their schools; that is, 'learning with teachers'. This is crucial to effective STEM leadership; students' understanding of and aspirations for future career paths in the STEM-associated fields relies upon principals, STEM leadership teams and teachers being aware of the opportunities and pathways towards their attainment.

9.3.1.5 Student STEM learning

Finally, PASL data (particularly survey data) highlighted important challenges that need to be addressed in future research, as well as embraced by school principals in their STEM vision and strategies for achieving equitable student engagement with, and achievement of, STEM learning outcomes. There are three aspects of this category.

17. Further investigation of the impacts of pressure that principals apply to teachers in relation to student achievement in mathematics and science is needed, in addition to an investigation of how negative impacts can be mitigated.

18. Longstanding issues, such as students' perceptions that boys are better than girls at mathematics and science, that mathematics is less interesting than science, and the decline of student interest in mathematics and science from primary school to secondary school, continue to require further and sustained attention.

19. Attention needs to be paid to increasing the extent to which STEM learning environments are experienced by students as intellectually challenging and fostering of curiosity.

9.4 Conclusion

The PASL Project affected principals' understandings of the requirements for implementing a vision for STEM education. Our research found that through their engagement with PASL PL (one of three programmes), principals have either developed new knowledge or nuanced their pre-existing understandings.

The Capability Sets (designed prior to the project and used as an organising framework for the development of the programmes, and the construction of research instruments, and data analysis) were found by principals to be an effective tool for framing their leadership responsibilities and actions. Data analysis using these capabilities also indicated areas of focus for future research and professional learning endeavours; notably, the critical importance of both principals' dispositions towards generating a positive STEM culture and taking a critical stance in relation to how they support STEM education in their schools. The Capability Sets also provided an holistic framework for approaches aimed at achieving a positive STEM culture, including the cascading model of capabilities directed at principals, teachers, students and the school community.

It was clear from interview data that although principals' understandings have been impacted by their participation in PASL, it is too early to obtain observable evidence of change in practice of teachers or students. However, it can be surmised that working with principals, as we did in PASL, is pivotal to bringing about changes in teachers' STEM capabilities, as to do so requires a whole-of-school STEM culture, which relies on leadership to drive change.

The four school case studies documenting exemplary practice in STEM teaching and learning provide evidence of innovative and effective leadership. The STEM Capability Sets also acted as a lens through which to view exemplary leadership practise; highlighting the importance of developing a STEM positive culture throughout the school and community, sourcing appropriate human and physical resources, and grounding their vision of STEM education in evidence-based practice.

PASL faced a number of challenges during the course of the three years it operated, but outcomes will inform both the structure and the content of future STEM education professional learning initiatives. As was the case in the PALL (Principals as Literacy Leaders) project, our data suggest that working with principals is a cost-effective way of impacting whole of school change and the development of teacher capabilities for supporting STEM learning.

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Appendix A: Survey Description of Measures and Descriptive Summaries

Appendix A provides contextual information and detailed results of the surveys conducted with principals, students, and teachers.

The following items are listed for Appendix A:

A.1 Principals Survey: Description of Measures
A.2 Principals: Descriptive Summaries and Significance Tests
A.3 Teacher Survey: Description of Measures
A.4 Teacher Survey: Descriptive Statistics and Correlations
A.5 Student Survey: Description of Measures
A.6 Student Survey: Descriptive Statistics and Correlations

A.1 Principals Survey: Description of Measures

The survey gathered as much data as practicable on a diversity of areas concerned with principals' perceptions of their own leadership, school culture, and beliefs about STEM (see Appendix A.2).

Measurement properties were adequate in terms of the reliabilities for all constructs except personality dimensions – Cronbach's α measure of internal consistency is reported for each measure at Time 1.

PERSONAL QUALITIES

These items were only asked at Time 1, prior to the PL.

Personality was measured by the 'Big-5' traits (Gosling, Rentfrow, & Swann, 2003). This short measure does not produce reliable factors; however, it is still widely used in the literature due to its economic format of 2 items per trait (10 items total):

Openness α = .42),

Conscientiousness (e.g., "I see myself as dependable, self-disciplined"; α = .72),

Extraversion α = .69),

Agreeableness α = .18), and

Neuroticism α = .58).

All items were rated on a 7-point Likert scale from 1 (Disagree strongly) to 7 (Agree strongly).

Priorities. Items from the Teaching and Learning International Survey (TALIS) (OECD, 2020) were used to ask about school spending priorities for 9 different areas (e.g., investing in ICT) rated from 1 (Of low importance), 2 (Of moderate importance), 3 (Of high importance). One item was adapted to be STEM-specific: "Investing in STEM professional learning for teachers".

LEADERSHIP STYLE

Transformational leadership has emerged as a promising approach to increasing demands for developing and implementing innovations in schools (Moolenaar, Daly, & Sleegers, 2010). In the PASL project, the scale by Carless, Wearing & Mann (2000) measured the extent to which principals felt they were able to foster a cooperative and supportive environment (7 items: e.g., "How often do you engage in the behaviours described below? Communicate a clear and positive vision of the future"; α = .85). All items were rated on a 5-point scale: 1 (Rarely or never), 2 (Sometimes), 3 (Often), 4 (Frequently), 5 (Very frequently, if not always).

Instructional leadership items (adapted to be STEM-specific from Tschannen-Moran & Gareis, 2004) measured principals' self-efficacy for the extent to which they were able to encourage positive learning in their schools (6 items: e.g., "In your current role as principal, to what extent can you facilitate student STEM learning in your school?"; α = .88). Items were rated on a 9-point scale: 1 (None at all), 3 (Very little), 5 (Some degree), 7 (Quite a bit), 9 (A great deal).

Principal support (e.g., "I listen to and support teachers' ideas and projects"; α = .59) and principal pressure (e.g., "I assess teachers mainly by their students' performance"; α = .69) were measured by 3 items each (Shibaz & Butler, 2011), were rated on a 5-point scale from 1 (Strongly disagree) to 5 (Strongly agree).

Data literacy was assessed using 5 items (Anderson, Leithwood & Strauss, 2010) related to how often data were used to inform practice (e.g., "I rely frequently on research evidence in my decision making"; α = .86). Items were rated on a 7-point Likert scale, 1 (Strongly disagree) to 7 (Strongly agree).

Feedback collection (α = .88) and Use of feedback (α = .81) were adapted to be STEM-specific from TALIS (OECD, 2020). Frequency of feedback collection and action on feedback in relation to STEM teaching and learning activities were the focus of 6 items. All ratings were from 1 (Never), 2 (Sometimes), and 3 (Frequently) – for use of feedback an additional scale point was added, 4 (Not used in this school).

Personal involvement was measured by 11 items regarding the extent to which principals were involved in the day-to-day proceedings of their school, including collaboration with teachers (OECD, 2020). All items were preceded by the stem "Please indicate how frequently you engaged in the following activities in this school during the last 12 months", rated 1 (Never or rarely), 2 (Sometimes), 3 (Often), 4 (Very often).

Need for professional learning was assessed using 12 items from TALIS (OECD, 2020), evaluating different areas in which principals felt they needed additional PL, including PL focussing on leadership. All were rated from 1 (No need at present), 2 (Low level of need), 3 (Moderate level of need), to 4 (High level of need).

SCHOOL ENGAGEMENT

Identification with school was assessed by the extent to which principals felt a sense of belonging, measured by 4 items (Chan, Lau, Nie, Lim & Hogan 2008; e.g., "Being a member of this school gives me a sense of pride"; α = .86). Items were rated on a 9-point scale, from 1 (None at all), 3 (Very little), 5 (Some degree), 7 (Quite a bit), to 9 (A great deal).

External Engagement items tapped principals' confidence across three areas outside of the school, using 3 items developed for the PASL project (e.g., "How confident are you that you have the ability to work with higher education institutions to encourage student development in STEM subjects?"; α = .87). Items were rated on a 7-point Likert scale from 1 (Not at all confident) to 7 (Extremely confident).

SCHOOL CULTURE

Collaborative team items (IES Teacher Survey (Wayman, Cho, Mandinach, Supovitz & Wilkerson, 2016)) measured the extent to which team efforts to improve aspects of the school were valued (5 items: e.g., "Members of my team respect colleagues who lead school improvement efforts"; α = .70). Items were rated on a 4-point scale from 1 (Strongly disagree) to 4 (Strongly agree).

Goal orientation was assessed for two facets (Midgley et al., 2000): 'Mastery' refers to a classroom in which mastery and understanding of learning are promoted (7 items: e.g., "In this school the importance of trying hard is really stressed to students"; α = .70), and 'Performance' emphasises competition and comparison of achievement between students (6 items: e.g., "In this school students are encouraged to compete with each other academically"; α = .74). All items were rated on a 5-point scale from 1 (Strongly disagree) to 5 (Strongly agree).

Collective efficacy items measured three interrelated facets:

- group competence (Goddard, 2002) involved judgements about the capabilities of teachers (6 items: e.g., "Teachers in this school are able to get through to difficult students"; α = .77), rated from 1 (Strongly disagree) to 6 (Strongly agree);
- task analysis (Goddard, 2002) related to students' readiness to learn (6 items: e.g., "These students come to school ready to learn; α = .77), rated from 1 (Strongly disagree) to 6 (Strongly agree); and
- an additional scale of collective efficacy, such as common beliefs about teaching and learning, was included from TALIS (OECD, 2020; 5 items), rated on a 5-point scale from 1 (Strongly disagree) to 5 (Strongly agree).

STEM BELIEFS

Beliefs about mathematics/science were each assessed using items by Watt (2004), including:

- intrinsic value (single item, how interesting they find the subjects; α = .91/.89);
- utility value (3 items: e.g., how useful they find the subjects α = .85/.78);
- attainment value (3 items: e.g., if being good at the subjects was important to who they are; α = .86/.91); and
- difficulty (3 items: e.g., the extent to which they consider the subjects to be difficult;
- α = .81/.75).

STEM PRACTICAL APPLICATIONS

Beliefs about tools items were developed by the PASL directors (based on Gulek, 1999) to target principals' beliefs about the use of tools in STEM classes (6 items: e.g., "How often do you use each of the following? Use of electrical equipment (e.g., computers, design programmes, robotic kits, calculators)"; α = .95). Items were rated on a 7-point Likert scale from 1 (Not at all) to 7 (Extremely).

STEM 21st Century skills examined the extent to which principals felt confident that teachers in their school could equip students with skills suited for life in the 21st Century. Items were adapted from the 21st Century Skills scale (Jia, Oh, Sibuma, LaBanca, & Lorentson, 2016) which targets skills of collaboration, communication, being a responsible citizen, problem solving, innovation and creativity. Each of the 11 items was adapted to mention the STEM learning context, to which principals were asked to respond prefaced by the stem "How confident are you in your STEM teachers' ability to do each of the following?" (e.g., "Collaborating with peers to achieve a goal on a STEM project"; α = .95). All items were rated on a 7-point Likert scale from 1 (Not at all confident) to 7 (Completely confident).

A.2 Principals: Descriptive Summaries and Significance Tests

Summary descriptive statistics are first presented for all measured constructs (overall, and per school level). Tests of statistical significance are reported for constructs that were measured both pre- and post-PL, to determine potential changes over time, or between primary/secondary/mixed school levels using repeated-measures analyses of variance and Tukey post hoc tests. The degree of relationship between STEM beliefs and dimensions of leadership style, school engagement and school culture were then explored using Pearson correlations, prior to and following the PL.

PERSONAL QUALITIES

Teachers' personality dimensions are presented in Table 18, showing descriptive statistics for principals overall, as well as according to primary, secondary, and mixed schools.

Generally, principals reported high positive traits (openness, conscientiousness, and agreeableness) and low for the negative trait of neuroticism. Extraversion was around the scale midpoint and showed the greatest variation.

Table 18: Principals' Personality Dimensions

	WHOLE SAMPLE *M (SD)*	PRIMARY *M (SD)*	SECONDARY *M (SD)*	MIXED *M (SD)*
Openness	5.77 (0.92)	5.58 (1.02)	6.31 (0.53)	5.70 (0.76)
Conscientiousness	6.11 (0.86)	6.03 (0.97)	6.44 (0.68)	5.90 (0.65)
Extraversion	4.61 (1.30)	4.58 (1.36)	4.63 (0.88)	4.70 (1.82)
Agreeableness	5.92 (0.63)	5.93 (0.69)	5.75 (0.53)	6.20 (0.45)
Neuroticism	2.32 (0.86)	2.38 (0.92)	2.06 (0.73)	2.50 (0.94)

1: Strongly disagree; 7: Strongly agree

PRIORITIES

To ascertain the priority principals placed on STEM improvements at their school relative to other valued issues, principals were asked at Time 1: "Thinking about your school as a whole, if the budget were to be increased by 5%, how would you rate the importance of the following spending priorities?", rated 1 *(Of low importance)*, 2 *(Of moderate importance)*, to 3 *(Of high importance)*.

Table 19 presents principals' priorities in order from most to least endorsed. Notably, "investing in STEM professional learning for teachers" was highest rated, implying the PASL project was an important investment for these principals who would like to see STEM PL for their teaching staff. Other highly rated priorities included supporting special needs students and investing in ICT. Among the least urgent were investing in instructional materials, reducing class sizes and improving teacher salaries.

Table 19: Areas of Priority for Future Investments

	WHOLE SAMPLE *M (SD)*	PRIMARY *M (SD)*	SECONDARY *M (SD)*	MIXED *M (SD)*
Investing in STEM professional learning for teachers	2.72 (0.46)	2.68 (0.48)	2.75 (0.46)	2.80 (0.45)
Supporting students with special needs	2.41 (0.62)	2.32 (0.67)	2.75 (0.46)	2.20 (0.45)
Investing in ICT	2.35 (0.66)	2.39 (0.70)	2.50 (0.54)	2.00 (0.71)
Supporting students from disadvantaged or migrant backgrounds	2.17 (0.84)	2.13 (0.84)	2.67 (0.58)	1.00 (0.00)
Reducing teachers' administration load by recruiting more support staff	2.16 (0.77)	2.16 (0.83)	2.13 (0.64)	2.20 (0.84)
Improving school buildings and facilities	1.92 (0.52)	1.88 (0.64)	2.00 (0.00)	2.00 (0.00)
Improving teacher salaries	1.78 (0.75)	1.79 (0.79)	1.50 (0.76)	2.20 (0.45)
Reducing class sizes from recruiting more staff	1.58 (0.67)	1.50 (0.54)	2.00 (1.00)	1.00 (0.00)
Investing in instructional materials (such as textbooks)	1.33 (0.49)	1.38 (0.52)	1.33 (0.58)	1.00 (0.00)

1: of low importance, 2: of moderate importance, 3: of high importance

LEADERSHIP STYLE

Transformational leadership significantly increased from before until after the PL, suggesting the PL may have encouraged principals to inspire and motivate their teachers to promote positive changes in their school.

While no significant changes were observed for instructional leadership, it had already been rated very high before the PL. Similarly, principal support was high. Principal pressure was rated around the midpoint, suggesting that principals felt they supported their teachers, but acknowledged the demands placed on them.

On average, principals reported close involvement in classrooms between 'sometimes' and 'often', reflected in 'sometimes' collecting and using feedback.

Table 20 reports means and standard deviations of Leadership style measures at Time 1 and Time 2, and accompanying univariate statistics. Statistically significant effects are highlighted in bold.

Table 21 reports means and standard deviations by school level at both timepoints. There were no statistically significant differences according to primary/secondary/mixed schools.

Table 20: Leadership Style: Pre- and post-professional learning

	Time 1	Time 2	*F*	*df*	*p*	η_p^2
Transformational leadership[a]	**4.16 (0.49)**	**4.37 (0.40)**	5.770	2, 30	.023*	.161
Instructional leadership[b]	6.86 (1.07)	6.80 (1.09)	1.030	2, 30	.318	.033
Principal support[c]	4.26 (0.57)	4.20 (0.67)	1.051	2, 30	.314	.034
Principal pressure[c]	2.57 (0.81)	2.61 (0.88)	1.568	2, 30	.220	.050
Personal involvement[d]	2.86 (0.52)	2.91 (0.41)	0.242	2, 30	.626	.008
Need for PL[e]	**2.47 (0.56)**	**2.27 (0.52)**	13.247	2, 30	.001*	.306
Feedback[g]						
Collecting	2.01 (0.44)	2.03 (0.44)	0.269	2, 30	.608	.009
Responding	2.15 (0.64)	2.08 (0.48)	0.525	2, 29	.205	.011

[a] 1: Rarely or never, 2: Sometimes, 3: Often, 4: Frequently, 5: Very frequently, if not always.
[b] 1: None at all, 3: Very little, 5: Some degree, 7: Quite a bit, 9: A great deal.
[c] 1: Strongly disagree, 5: Strongly agree.
[d] 1: Never or rarely, 2: Sometimes, 3: Often, 4: Very often.
[e] 1: No need at present, 2: Low level of need, 3: Moderate level of need, 4: High level of need.
[g] 1: Never, 2: Sometimes, 3: Frequently.

Table 21: Leadership Style: School level differences and changes over time

	Primary T1	Secondary T1	Mixed T1	Primary T2	Secondary T2	Mixed T2
Transformational leadership	4.25 (0.51)	4.04 (0.46)	3.97 (0.38)	4.43 (0.37)	4.27 (0.54)	4.30 (0.27)
Instructional leadership	6.86 (1.07)	7.35 (0.77)	6.10 (1.24)	7.09 (0.83)	6.56 (1.38)	6.00 (1.22)
Principal support	4.30 (0.59)	4.25 (0.65)	4.10 (0.41)	4.33 (0.63)	4.06 (0.90)	3.90 (0.22)
Principal pressure	2.55 (0.84)	2.79 (0.75)	2.27 (0.83)	2.48 (0.89)	2.67 (0.82)	3.07 (0.92)
Personal involvement	2.90 (0.59)	2.92 (0.39)	2.62 (0.42)	2.98 (0.39)	2.81 (0.25)	2.78 (0.65)
Need for PL	2.34 (0.58)	2.59 (0.56)	2.82 (0.26)	2.82 (0.26)	2.15 (0.39)	2.63 (0.31)
Feedback						
Collecting	2.11 (0.36)	1.98 (0.61)	1.70 (0.42)	2.10 (0.36)	1.83 (0.58)	2.00 (0.53)
Responding	2.05 (0.46)	2.22 (0.62)	1.70 (0.42)	2.23 (0.43)	1.89 (0.56)	1.90 (0.28)

The reported need for PL decreased statistically significantly following the PL (see Table 22), suggesting that principals felt the PASL programme had reduced their need for PL.

Specifically, in relation to each listed PL, needs decreased significantly for providing effective feedback, promoting equality and diversity, developing teacher collaboration, and human resource management.

Table 22: Needs for PL: Pre- and post-professional learning

	Time 1	Time 2	*F*	*df*	*p*	η_p^2
Providing effective feedback	**2.94 (0.75)**	**2.61 (0.70)**	7.838	1, 30	**.009***	.207
Developing teacher collaboration	**2.76 (0.93)**	**2.27 (0.67)**	21.315	1, 30	**<.001***	.415
Designing professional development for teachers	2.64 (0.60)	2.55 (0.71)	0.097	1, 30	.758	.003
Observing classroom instruction	2.52 (0.67)	2.39 (0.61)	0.714	1, 30	.405	.023
Data use	2.45 (0.79)	2.48 (0.93)	0.253	1, 30	.407	.058
Designing school curriculum	2.45 (0.71)	2.30 (0.64)	3.187	1, 30	.084	.096
Knowledge about new leadership research	2.36 (0.74)	2.30 (0.77)	0.074	1, 30	.787	.002
Human resource management	**2.33 (0.89)**	**2.03 (0.81)**	7.069	1, 30	**.012***	.191
Understanding of national/local policies	2.33 (0.74)	2.09 (0.77)	1.660	1, 30	.207	.052
Promoting equality and diversity	**2.24 (0.87)**	**1.97 (0.73)**	5.750	1, 30	**.023***	.161
Financial management	2.15 (0.94)	2.06 (0.86)	0.467	1, 30	.500	.015

1: No need at present, 2: Low level of need, 3: Moderate level of need, 4: High level of need.

SCHOOL ENGAGEMENT

Overall, principals reported very high identification with their school at both timepoints, indicating they felt very strongly that they 'belonged' at their current school. External engagement was moderately rated overall. There were no statistically significant changes in either construct across the two timepoints.

Table 23 reports means and standard deviations for school engagement measures at Time 1 and Time 2, and accompanying univariate statistics.

Table 23: School Engagement: Pre- and post-professional learning

	Time 1	Time 2	*F*	*df*	*p*	η_p^2
Identification with school[a]	8.56 (0.62)	8.65 (0.59)	2.418	2, 30	.130	.075
External engagement[b]	4.67 (1.49)	4.67 (1.42)	0.700	2, 30	.409	.023

[a] 1: None at all, 3: Very little, 5: Some degree, 7: Quite a bit, 9: A great deal.
[b] 1: Not at all confident, 7: Extremely confident.

A significant difference between school level (primary/secondary/mixed) was observed for external engagement, which principals of mixed schools reported as significantly lower; however, given the small number of mixed school principals (n = 5), further research would be necessary to replicate those results.

Table 24 reports means and standard deviations by school level across both timepoints. Significant differences are highlighted in bold.

Table 24: School Engagement: School level differences and changes over time

	Primary T1	Secondary T1	Mixed T1	Primary T2	Secondary T2	Mixed T2
Identification	8.58 (0.63)	8.63 (0.53)	8.45 (0.80)	8.59 (0.62)	8.78 (0.53)	8.70 (0.67)
External engagement*	4.68 (1.35)	5.67 (1.15)	**3.00 (1.11)**	4.47 (1.25)	5.58 (1.59)	**4.00 (1.31)**

* A main between-subjects effect was observed: F(2, 30) = 5.710, p = .008, η_p^2 = .276.School culture.

Table 25 reports descriptive statistics for school culture factors at Times 1 and 2, and accompanying statistical significance tests. There were no statistically significant changes from prior to, versus following, the PL.

Means for collaborative teams were above the midpoint, suggesting that principals in the PASL project worked closely with their teachers and other staff. Mastery goals were more highly endorsed than performance goals overall. Collective efficacy was generally above the midpoint, indicating an environment where the principal shared confidence in teachers' and students' capabilities.

Table 25: School Culture: Pre- and post-professional learning

	Time 1	Time 2	*F*	*df*	*p*	η_p^2
Collaborative teams[a]	3.08 (0.36)	3.05 (0.40)	0.060	2, 30	.808	.002
Goal orientation[b]						
Mastery	4.39 (0.52)	4.40 (0.54)	0.002	2, 30	.961	<.001
Performance	2.97 (0.76)	3.05 (0.77)	0.108	2, 30	.745	.004
Collective efficacy						
Group competence[c]	5.17 (0.49)	5.20 (0.56)	0.001	2, 30	.979	<.001
Task analysis[c]	4.84 (0.74)	4.67 (0.83)	1.147	2, 30	.293	.037
TALIS[a]	3.92 (0.45)	3.97 (0.44)	0.391	2, 30	.536	.013

[a] 1: Strongly disagree, 4: Strongly agree.
[b] 1: Not at all true, 5: Very true.
[c] 1: Strongly disagree, 6: Strongly agree.

Table 26 reports descriptive statistics according to school level at both timepoints. There was one statistically significant school-level effect, where primary school principals reported significantly lower Performance goal orientation than principals at secondary or mixed schools (highlighted in bold). These results mirrored the student responses, where a pattern of lower Performance goals in primary than secondary school was observed (see Appendix A.6). There was no significant difference in Mastery goals, which were reported as high by principals across different school levels; nor any differences for collaborative teams or collective efficacy factors.

Table 26: School Culture: School level differences and changes over time

	Primary T1	Secondary T1	Mixed T1	Primary T2	Secondary T2	Mixed T2
Collaborative teams	3.10 (0.39)	3.05 (0.33)	3.08 (0.36)	3.07 (0.46)	2.96 (0.37)	3.16 (0.17)
Goal orientation						
Mastery	4.52 (0.47)	4.18 (0.59)	4.20 (0.53)	4.53 (0.48)	4.21 (0.48)	4.17 (0.77)
Performance*	**2.67 (0.53)**	3.40 (0.73)	3.53 (1.00)	**2.80 (0.58)**	3.40 (0.73)	3.50 (1.17)
Collective efficacy						
Group competence	5.27 (0.54)	4.96 (0.42)	5.10 (0.28)	5.34 (0.44)	4.89 (0.74)	5.10 (0.55)
Task analysis	4.86 (0.75)	4.88 (0.58)	4.70 (1.04)	4.63 (0.84)	4.73 (0.71)	4.70 (1.10)
TALIS	4.01 (0.43)	3.83 (0.57)	3.72 (0.23)	4.09 (0.40)	3.75 (0.33)	3.84 (0.44)

* A main between-subjects effect was observed: $F(2, 30) = 4.690$, $p = .017$, $\eta_p^2 = .238$.

STEM BELIEFS

Intrinsic/utility/attainment values and perceived difficulty beliefs in relation to each of mathematics and science, and entity beliefs per each domain, are reported in Table 27 at both timepoints, together with accompanying univariate statistics. Significant differences are highlighted in bold.

A significant decrease in principals' intrinsic value for mathematics (that is, interest and enjoyment) was observed following the PL. Upon further inspection, this was accounted for by a significant interaction effect with school level (see Table 28), whereby only principals at mixed schools reported a drop in their intrinsic value for mathematics, although principals at primary and secondary schools did not. Caution must be exercised in interpreting this effect, due to the small number of mixed school principals in the sample as previously mentioned.

Principals reported high intrinsic value for science, compared with moderate intrinsic value for mathematics. Utility and attainment values, and perceived difficulty, were similar across mathematics and science domains. Principals valued both as highly useful, held moderate attainment values for both, and considered both moderately difficult.

Principals across all school levels reported perceiving science as less difficult following the PL, indicating a positive change in principals' perceptions about science.

Principals reported low 'Entity beliefs' about mathematics and science (that is, that students' abilities could not change), which did not change following the PL. At both timepoints, principals held adaptive 'Incremental beliefs', that students can improve their abilities in both mathematics and science.

Table 27: STEM Beliefs: Pre- and post-professional learning

	Time 1	Time 2	*F*	*df*	*p*	η_p^2
Mathematics beliefs[a]						
Intrinsic*	**4.61 (1.42)**	**4.48 (1.64)**	5.304	2, 28	.029*	.159
Utility	6.11 (0.63)	6.22 (0.70)	1.641	2, 28	.211	.055
Attainment	4.39 (1.51)	4.45 (1.56)	0.302	2, 28	.587	.011
Difficulty	4.09 (1.34)	3.96 (1.58)	1.209	2, 28	.281	.041
Science beliefs[a]						
Intrinsic	5.44 (1.10)	5.54 (1.18)	0.625	2, 28	.436	.022
Utility	6.17 (0.63)	6.14 (0.77)	0.001	2, 28	.873	.010
Attainment	4.30 (1.42)	4.38 (1.74)	0.020	2, 28	.888	.001
Difficulty	**4.08 (1.16)**	**3.72 (1.27)**	5.133	2, 28	.031*	.155
Entity beliefs[b]						
Mathematics	2.35 (1.04)	2.13 (1.08)	0.327	2, 28	.572	.012
Science	2.15 (1.01)	2.16 (1.03)	0.063	2, 28	.803	.002

[a] 1: Not at all, 7: Extremely; [b] 1: Strongly disagree, 6: Strongly agree.
* A significant interaction was observed between timepoints and school level (primary / secondary / mixed): $F(2, 28) = 4.532$, $p = .023$, $\eta_p^2 = .237$.

Table 28 reports descriptive statistics according to school level at both timepoints. There were no other statistically significant effects than the mathematics intrinsic value decline among principals at mixed schools outlined above.

Table 28: STEM Beliefs: School level differences and changes over time

	Primary T1	Secondary T1	Mixed T1	Primary T2	Secondary T2	Mixed T2
Mathematics beliefs						
Intrinsic	4.88 (1.45)	4.38 (0.76)	**3.93 (1.95)**	4.98 (1.35)	4.19 (1.30)	**3.00 (2.32)**
Utility	6.16 (0.58)	6.29 (0.76)	5.67 (0.58)	6.19 (0.70)	6.43 (0.74)	6.00 (0.75)
Attainment	4.53 (1.66)	4.57 (0.63)	3.60 (1.79)	4.52 (1.47)	4.76 (0.90)	3.73 (2.56)
Difficulty	3.63 (1.21)	5.05 (0.45)	4.47 (1.98)	3.56 (1.42)	4.88 (0.79)	4.17 (2.54)
Science beliefs						
Intrinsic	5.67 (0.78)	5.76 (1.03)	4.13 (1.50)	5.70 (0.88)	5.86 (1.12)	4.47 (1.80)
Utility	6.21 (0.65)	6.24 (0.63)	5.93 (0.60)	6.14 (0.70)	6.19 (1.05)	6.07 (0.80)
Attainment	4.40 (1.48)	4.62 (0.56)	3.47 (1.91)	4.53 (1.60)	4.67 (1.44)	3.40 (2.55)
Difficulty	3.61 (1.06)	4.95 (0.59)	4.67 (1.33)	3.47 (1.32)	4.14 (1.02)	4.07 (1.38)
Entity beliefs						
Mathematics	2.49 (1.07)	2.10 (1.01)	2.20 (1.10)	2.12 (1.12)	1.95 (1.04)	2.40 (1.14)
Science	2.18 (1.04)	2.05 (1.01)	2.20 (1.10)	2.28 (1.11)	1.95 (1.04)	2.00 (0.71)

STEM PRACTICAL APPLICATIONS

There were no significant changes following the PL in principals' beliefs about either the use of tools beneficial to students' STEM learning, nor in teachers equipping their students with the skills necessary to meet the STEM demands of the 21st Century. Table 29 reports descriptive statistics for principals' beliefs about tools and 21st Century skills at both timepoints, and accompanying univariate statistics.

Table 29: STEM Practical Applications: Pre- and post-professional learning

	Time 1	Time 2	*F*	*df*	*p*	η_p^2
Beliefs about tools[a]	5.51 (1.03)	5.49 (0.93)	0.007	2, 29	.933	<.001
21st Century skills[a] [1]	5.03 (1.00)	5.06 (0.82)	0.978	2, 28	.331	.034

[a] 1: Not at all, 7: Extremely.

[1] A significant interaction was observed between timepoints and school level (primary / secondary / mixed): $F(2, 28) = 4.131$, $p = .027$, $\eta_p^2 = .034$.

Table 30 reports descriptive statistics for each school level at both timepoints. There was an interaction with school level, where principals at mixed schools reported a decline for 21st Century skills from Time 1 to Time 2; however, given both the small number of principals at mixed schools as already discussed, together with the nature of mixed schools involving both primary and secondary students, this comparison may not be very illuminating, as primary students may be less equipped (due to being younger) and secondary students more prepared (due to being closer to leaving school).

Table 30: STEM Practical Applications: School level differences and changes over time

	Primary T1	Secondary T1	Mixed T1	Primary T2	Secondary T2	Mixed T2
Beliefs about tools	5.67 (0.89)	5.71 (1.05)	4.60 (1.21)	5.62 (0.78)	5.59 (0.92)	4.80 (1.33)
21st Century skills	4.94 (1.12)	5.04 (0.96)	**5.36 (0.53)**	5.20 (0.80)	5.32 (0.59)	**4.16 (0.65)**

RELATIONSHIPS AMONG PRINCIPALS' STEM BELIEFS, LEADERSHIP STYLE AND SCHOOL CULTURE

To examine the extent of relationship between principals' STEM beliefs with their leadership style and school culture dimensions, Pearson correlations were computed pre- and post-PL (see Table 31). Asterisked relationships indicate those which were statistically significant (bold and underlined for emphasis), summarised below. Correlations can range from 0 (no relationship) to ±1 (perfect correspondence); positive numbers indicate a same direction of relationship and negative numbers the opposite.

Prior to the PL intrinsic value for mathematics was statistically significantly moderately and positively correlated with principals reported personal involvement with the day-to-day activity of the school, whereas perceiving mathematics as difficult was negatively correlated with their personal involvement. For science, intrinsic value showed significant moderate positive associations with principals' data literacy and feedback collecting practices; valuing science as useful also associated with feedback collecting.

Following the PL, a greater number of significant correlations was evident. For both mathematics and science:

- All beliefs (except entity) associated with principals' instructional leadership: positively with all value dimensions (intrinsic/utility/attainment), negatively with perceived difficulty.
- Utility value (positively) and perceived difficulty (negatively) related to the group competence facet of collective efficacy (for example, "The school staff share a common set of beliefs about teaching and learning").
- Entity beliefs (believing that mathematics / science abilities are fixed and cannot change) also negatively related to principals' reported group competence facet of collective efficacy, and data literacy practices where principals used data to inform their decision-making.

For mathematics only, following the PL, Intrinsic value positively associated with principals' external engagement (including families, local businesses, and nearby tertiary institutions), utility value with use of collaborative teams, and attainment value with external engagement and pressure for student achievement.

Table 31: Relationships Among Principals' STEM Beliefs, Leadership Style, and School Culture Dimensions

	T1 Mathematics beliefs					T1 Science beliefs				
Time 1	Intrinsic	Utility	Attainment	Difficulty	Entity	Intrinsic	Utility	Attainment	Difficulty	Entity
Transformational l'ship	.32	.29	.06	-.24	-.09	.23	.08	-.01	-.26	-.09
Instructional leadership	.34	.20	.14	-.09	-.16	.28	-.09	-.04	.08	-.09
Principal support	.03	.30	-.07	.00	-.15	.26	.28	-.13	-.15	-.10
Principal pressure	.35	.11	.34	-.09	-.04	.29	.03	.31	-.03	.23
External engagement	.05	.06	.04	.15	-.02	.17	.00	.04	.23	.07
Personal involvement	**.52****	.13	.34	**-.46****	-.24	.19	-.21	-.08	-.25	.08
Collaborative teams	.34	.31	.33	-.18	-.33	.14	-.02	.05	-.33	-.09
Data literacy	.21	.23	.27	-.24	.29	**.46***	.24	.23	.12	.24
Feedback collecting	.23	.07	.03	.08	.06	**.59****	**.48****	.27	-.14	.02
Feedback responding	.11	.23	.17	-.03	-.02	-.04	-.05	-.02	-.18	-.04
Mastery goals	.00	.18	-.11	.04	.04	.27	.34	.02	.14	-.15
Performance goals	.10	.00	.14	.26	-.11	.02	.09	.17	.24	.04
Coll.-eff: Group competence	.13	.28	.07	-.15	.11	.22	.19	.04	-.02	.00
Coll.-eff: Task analysis	-.06	.10	.10	.17	.09	.22	.29	.12	-.02	.05
Collective efficacy: TALIS	.25	.21	.12	-.18	-.08	.00	.00	-.20	-.16	-.02
	T2 Mathematics beliefs					**T2 Science beliefs**				
Time 2	Intrinsic	Utility	Attainment	Difficulty	Entity	Intrinsic	Utility	Attainment	Difficulty	Entity
Transformational l'ship	-.07	.21	-.21	.10	-.02	-.11	-.03	-.33	-.02	-.06
Instructional leadership	**.63****	**.35***	**.39***	**-.43***	-.31	**.56****	**.40***	**.38***	**-.41***	-.05
Principal support	.07	.05	.11	.06	-.01	.18	.16	.13	-.04	.04
Principal pressure	.13	.08	**.52****	-.23	-.08	-.14	-.01	.29	.05	.14
External engagement	**.35***	.32	**.41***	-.24	-.20	.19	.08	.18	-.13	-.05
Personal involvement	.28	.21	.12	-.24	-.07	.14	.14	.04	-.20	.08
Collaborative teams	.27	**.37***	.19	-.22	-.23	.00	.15	.02	-.12	-.27
Data literacy	.29	.30	.26	-.07	**-.52****	.20	.21	.08	.02	**-.46****
Feedback collecting	.05	.12	.12	-.15	.19	-.05	.15	.14	-.06	.25
Feedback responding	.12	.13	.08	-.21	.11	.02	.03	.06	-.14	.25
Mastery goals	.21	.28	.05	-.18	-.26	.08	.14	-.07	.04	-.24
Performance goals	-.13	.07	.13	.06	.16	-.18	-.01	.14	.09	.08
Coll.-eff: Group competence	.33	**.40***	.07	-.07	**-.39***	.29	**.49****	.02	-.03	**-.44***
Coll.-eff: Task analysis	.02	.17	.16	.09	.16	-.06	.08	.22	.27	.16
Collective efficacy: TALIS	.14	.21	-.02	-.05	-.15	-.08	.07	-.06	-.09	-.13

(* $p < .05$, ** $p < .01$, Listwise N = 33)

A.3 Teacher Survey: Description of Measures

Teacher attitudes towards mathematics and science

Beliefs assessed using items by Watt (2004), including:

- intrinsic value (3 items: e.g., how interesting they find the subjects, α = .91/.89);
- utility value (3 items: e.g., how useful they find the subjects, α = .77/.85);
- attainment value (3 items: e.g., if being good at the subjects was important to who they are;
- α = .84/.90); and perceived difficulty (3 items: e.g., the extent to which they consider the subjects to be difficult, α = .63/.79).

Entity beliefs tapped whether teachers believed students' abilities were innate and fixed ('entity beliefs'), versus learned and controllable ('incremental beliefs'). Lower scores indicate entity, and higher scores incremental beliefs (adapted to be STEM-specific from Dweck, Chiu & Hong, 1995, α = .72/.89). All items were rated on a 5-point scale from 1 (Strongly disagree) to 6 (Strongly agree).

Teacher instruction in mathematics and science

The extent to which teachers academically challenged their students in each of STEM discipline or integrated STEM, was measured by 3 items developed specifically for the PASL project (based on items from Conley, Pintrich, Vekiri, & Harrison, 2004; e.g., "I push students to be curious and think about how things work in maths/science"; α = .82/.86). All items were rated on a 5-point scale from 1 (Strongly disagree) to 5 (Strongly agree).

Enthusiasm for teaching each discipline was assessed with 3 items developed specifically for the PASL project (adapted from Kunter, Frenzel, Nagy, Baumert & Pekrun, 2011; e.g., "I really enjoy teaching maths/science"; α = .91/.91).

Data literacy activities in discipline were measured by 4 items developed specifically for the PASL project (based on items from Anderson et al., 2010; e.g., "How often do these things happen in your maths/science lessons? Students draw on data and evidence to make decisions", α = .63/.61). All items were rated on a 4-point scale, from 1 (Never or almost never), 2 (Some lessons), 3 (Many lessons), to 4 (Every lesson or almost every lesson).

- Two facets of teacher practice drawn from OECD (2016b) items encompassed inquiry learning (5 items: α = .69/.69) and teacher-directed learning (4 items: α = .71/.72). Items were prefaced by the stem "How often do these things happen in your school (STEM subject) lessons?", rated 1 (Never or almost never), 2 (Some lessons), 3 (Many lessons), to 4 (Every lesson or almost every lesson).
- Inquiry learning measured whether students undertook work in which they could draw their own, independent conclusions (e.g., "Students carry out practical work").

Teacher-directed learning involved how involved teachers are in their students' learning (e.g., "A whole class discussion takes place in which I participate").

SCHOOL CULTURE

Principal support (e.g., "The principal listens to and support teachers' ideas and projects"; α = .83) and principal pressure (e.g., "The principal assesses teachers mainly by their students' performance"; α = .73) were measured by 3 items each (Shibaz & Butler., 2011), were rated on a 5-point scale from 1 (Strongly disagree) to 5 (Strongly agree).

External Engagement items tapped teachers' confidence across three areas outside of the school, using 3 items developed for the PASL project (e.g., "How confident are you that you have the ability to work with higher education institutions to encourage student development in STEM subjects?"; α = .93). Items were rated on a 7-point Likert scale from 1 (Not at all confident) to 7 (Extremely confident).

PERCEIVED EFFICACY

Self-efficacy in STEM subjects, such as teaching which supported students to value learnings, were measured by 14 items adapted from TALIS (OECD, 2020) to be STEM-specific.

STEM 21st Century skills examined the extent to which teachers felt confident that they could equip students with skills suited for life in the 21st Century. Items were adapted from the 21st Century Skills scale (Jia et al., 2016) which targets skills of collaboration, communication, being a responsible citizen, problem solving, innovation and creativity. Each of the 11 items was adapted to mention the STEM learning context, to which teachers were asked to respond prefaced by the stem "How confident are you in each of the following?" (e.g., "Engaging students in collaborating with peers to achieve a goal on a STEM project"; α = .95). All items were rated on a 7-point Likert scale from 1 (Not at all confident) to 7 (Completely confident).

- Collective efficacy items measured two interrelated facets:
- group competence (Goddard, 2002) involved judgements about the capabilities of teachers (6 items: e.g., "Teachers in this school are able to get through to difficult students"; α = .78), rated from 1 (Strongly disagree) to 6 (Strongly agree); and

task analysis (Goddard, 2002) related to students' readiness to learn (6 items: e.g., "These students come to school ready to learn; α = .76), rated from 1 *(Strongly disagree)* to 6 *(Strongly agree)*.

TEACHERS' GOALS

- Teachers' goal orientations (Butler, 2007, 2012) targeted three interrelated factors. Items were prefaced by the stem, "Teachers differ in what makes them feel they had a successful day; when would you feel that you had a successful day?", each rated on a scale from 1 *(Strongly disagree)* to 5 *(Strongly agree)*;
- *mastery goals*, relating to teachers orienting their goals to strive for and acquire improved abilities and skills (e.g., "I learned something new about teaching or myself as a teacher");
- *work avoidance goals*, relating to teachers avoiding work-related tasks (e.g. "I didn't have to spend much time preparing lessons)"; and
- *relational goals*, relating to teachers creating genuine interpersonal relationships with their students (e.g., "My main goal as a teacher is to show my students that I care about them").

STUDENT ENGAGEMENT IN MATHEMATICS AND SCIENCE

Teacher-reported students' curiosity in each of their mathematics and science classes was included as an outcome variable, measured by two items developed specifically for the PASL project (based on items from Frenzel, Pekrun, Dicke & Goetz, 2012; e.g., "After a maths/science class, students are often curious about what we are going to do next lesson", α = .73/.80). Items were rated on a 5-point scale from 1 (Strongly disagree) to 5 (Strongly agree).

A.4 Teacher Survey: Descriptive Statistics and Correlations

Summary descriptive statistics are presented for all measured constructs, first for teachers of mathematics and science, and then for teachers of design & technology, digital technology, and integrated STEM.

MATHEMATICS AND SCIENCE TEACHER SURVEY RESULTS

Attitudes in mathematics and science

Attitudes towards mathematics and science are reported in Table 32. Overall, teachers reported high intrinsic value, high utility value, and moderate attainment value in both mathematics and science, indicating that they personally felt that mathematics and science are valuable. They also reported that they found mathematics and science to be somewhat difficult, with average scores around the midpoint.

Teachers also reported low 'entity beliefs' about mathematics and science (that is, that students' abilities could not change). Instead, teachers held adaptive 'incremental beliefs', that students can improve their abilities in mathematics and science, respectively.

Table 32: Attitudes

	Mathematics Whole sample *M* (SD)	**Science Whole sample *M* (SD)**
	n = 80	*n*=76
Intrinsic value[b]	5.88 (1.12)	6.13 (0.75)
Utility value[b]	6.61 (0.48)	6.40 (0.79)
Attainment value[b]	5.32 (1.33)	5.62 (1.34)
Difficulty[b]	3.37 (1.18)	3.51 (1.38)
Entity beliefs[a]	1.78 (0.98)	1.61 (0.87)

[a] 1: Strongly disagree, 7: Strongly agree
[b] 1: Not at all, 7: Extremely.

Instruction in mathematics and science

Instruction in mathematics and science are reported in Table 33.

Overall, teachers reported that their students were not very curious in mathematics, and moderately curious in science. Teachers provided moderate levels of academic challenge in each of mathematics/science and were highly enthusiastic in their teaching.

Data literacy and inquiry learning practices occurred "some lessons" in mathematics, and between "some" and "many lessons" in science. Teacher-directed instruction occurred between "many" and "every lesson" in both mathematics and science classrooms.

Table 33: Instruction (Mathematics)

	Mathematics Whole sample *M* (SD)	**Science Whole sample *M* (SD)**
	n = 80	*n=76*
Curiosity[a]	3.33 (0.84)	4.08 (0.69)
Academic challenge[a]	4.16 (0.68)	4.35 (0.61)
Teacher enthusiasm[b]	6.38 (0.75)	6.42 (0.75)
Data literacy[c]	2.24 (0.52)	2.45 (0.58)
Inquiry learning[c]	2.09 (0.53)	2.48 (0.45)
Teacher-directed learning[c]	3.44 (0.51)	3.30 (0.51)

[a] 1: Strongly agree, 7: Strongly disagree; [b] 1: Not at all, 7: Completely; [c] 1: Never or almost never, 2: Some lessons, 3: Many lessons, 4: Every lesson.

School culture: mathematics and science teachers

Descriptive statistics of school culture are reported in Table 34, across the whole sample.

Teachers reported positively about the leadership in their school, with means slightly above the midpoint on principal support. There was some level of reported pressure from principals placed on teachers, but this was consistently below the midpoint.

Teachers also displayed moderate self-efficacy beliefs regarding their own teaching abilities, and similarly for their colleagues' teaching abilities. Teachers felt moderately confident in collaborating with external sources (for example, universities, parents), and that they were preparing their students well for the demands of the 21st Century.

Finally, teachers demonstrated positive goal orientations. Mastery and relational goals were above the midpoint, while negative 'work avoidance' goals were low rated.

Table 34: School culture descriptives

	Whole sample *N* = 196 *M* (SD)
School leadership	
Principal support[a]	4.04 (0.82)
Principal pressure[a]	2.55 (0.87)
Efficacy beliefs	
Self-efficacy[c]	3.21 (0.45)
External engagement[b]	4.31 (1.45)
21st Century skills[b]	5.15 (1.04)
Collective efficacy – group competence[a]	5.04 (0.81)
Collective efficacy – task analysis[a]	4.67 (0.79)
Goals	
Relational[a]	4.11 (0.71)
Mastery approach[a]	4.28 (0.51)
Work avoidance[a]	2.21 (0.86)

[a] 1: Strongly disagree, 5: Strongly agree; [b] 1: Not at all confident, 7: Extremely confident; [c] 1: Not at all, 2: To some extent, 3: Quite a bit, 4: A lot.

Relationships among school culture and teachers' classroom practices

To examine the extent of relationship between teachers' classroom practices/beliefs and school culture, Pearson correlations were computed between these factors (see Tables 35, 36, 37). Asterisked relationships indicate those which were statistically significant, summarised below. Correlations can range from 0 (no relationship) to ±1 (perfect correspondence); positive numbers indicate a same direction of relationship and negative numbers the opposite. Interpreted correlations below are those statistically significant at $p < .05$.

Mathematics teachers:

Principal's support promoted teachers' use of data literacy and teacher-directed instructional practices.

Principal pressure restrained teachers' use of data literacy practices.

Science teachers:

Teachers' external engagement strongly promoted teaching practices of academic challenge, enthusiasm, inquiry learning and teacher-directed learning activities.

Relationships among teachers' efficacy beliefs and goals, with classroom practices and beliefs about mathematics/science.

MATHEMATICS:

- Teachers' self-efficacy regarding their own teaching abilities was moderately to highly positively related to academic challenge, teacher enthusiasm, data literacy, and incremental "growth" beliefs (thus, lower entity beliefs).
- Confidence in conveying 21st Century skills to students was moderately positively correlated with teaching practices of providing academic challenge, inquiry learning, and data literacy activities; it also related to higher teaching enthusiasm, and more incremental growth beliefs about students' mathematical abilities.
- Beliefs about colleagues' teaching abilities ("Group competence") had a moderate positive relationship with teachers providing data literacy activities, teaching enthusiasm, and incremental growth beliefs.
- Teachers' relational goals to develop caring relationships with students, were positively moderately correlated with both data literacy and inquiry learning activities, as well as the utility value they attached to mathematics.
- Mastery goals, to improve their own instruction, related to more provision of academic challenge, teaching enthusiasm, and inquiry learning activities.
- Work avoidance goals associated with less enthusiasm for teaching.

SCIENCE:

- Self-efficacy for science teachers' own teaching abilities was moderately to highly positively related to all but one of the measured instructional practices; namely, academic challenge, teaching enthusiasm, inquiry learning and teacher-directed learning.
- Similar relationships were observed with teachers' confidence to develop students' 21st Century skills; for all measured instructional practices (including data literacy activities).
- Teachers' confidence to develop students' 21st Century skills also related to all measured science beliefs; positively with intrinsic, utility and attainment values, and negatively with perceiving science as difficult.
- Group competence was moderately negatively associated with attainment value (that is, perceived personal value for science).
- Mastery goals moderately positively correlated with all measured instructional practices except inquiry learning; also correlated to teachers' own utility and attainment values for science.
- Work avoidance goals were higher for teachers who found science to be more difficult.

Relationships with student outcomes

MATHEMATICS:

- Instructional practices that benefitted students' curiosity in mathematics, were: level of academic challenge, teacher enthusiasm, data literacy and inquiry learning activities; not, teacher-directed mathematical instruction. Most beneficial was academic challenge.
- Teachers' own level of interest (intrinsic value) and perceived personal importance of science (attainment value) promoted students' curiosity in mathematics; teachers who perceived mathematics to be more difficult dampened students' curiosity.

SCIENCE:

- All measured instructional practices benefitted students' curiosity in science: level of academic challenge, teacher enthusiasm, data literacy and inquiry learning activities, as well as teacher-directed science instruction. Most beneficial was academic challenge.
- Teachers' intrinsic value for science promoted students' curiosity in science; teachers who perceived science to be more difficult dampened students' curiosity.

Table 35: Mathematics correlations with school climate

	School leadership			Efficacy beliefs				Goals		
	Principal support	Principal pressure	External engagement	Self-efficacy	21st Century skills	Collective efficacy – Group competence	Collective efficacy – Task analysis	Relational	Mastery	Work avoidance
Instruction										
Academic challenge	.21	-.11	.19	.50**	.36**	.19	.21	.13	.24*	.01
Teacher enthusiasm	.09	.03	.16	.30**	.27*	.23*	.20	.18	.27*	-.27*
Data literacy	.28*	-.24*	.17	.35**	.25*	.29**	.23*	.29**	.19	.01
Inquiry learning	.10	.02	-.15	.17	.29**	.16	-.03	.31**	.23*	-.07
Teacher-directed learning	.23*	-.06	-.24	.22	.02	.14	.09	.12	-.03	-.05
Mathematics beliefs										
Intrinsic	-.06	-.05	.23	.16	.08	.13	.09	-.10	.05	-.21
Utility	.15	.06	-.14	.22	.05	.14	.17	.28*	.22	-.16
Attainment	.06	.02	-.03	.11	.05	.11	.13	.18	.17	.04
Difficulty	-.03	.13	.12	-.14	-.23*	-.10	-.05	-.12	.19	.13
Entity	.16	-.04	.27	.40**	.32**	.23*	.16	.16	.10	-.21

Listwise N = 80; * $p < .05$; ** $p < .01$

Table 36: Science correlations with school climate

	School leadership			Efficacy beliefs				Goals		
	Principal support	Principal pressure	External engagement	Self-efficacy	21st Century skills	Collective efficacy – Group competence	Collective efficacy – Task analysis	Relational	Mastery	Work avoidance
Instruction										
Academic challenge	-.03	.14	.56**	.51**	.61**	.02	.07	-.07	.29*	-.06
Teacher enthusiasm	-.05	.05	.59**	.42**	.63**	-.08	-.04	-.08	.29*	-.05
Data literacy	.01	.19	.32	.20	.36**	.12	.10	.13	.31**	-.01
Inquiry learning	.01	.16	.64**	.23*	.46**	.18	.16	-.01	.18	-.10
Teacher-directed learning	-.03	.12	.50*	.48**	.30**	.11	.06	-.06	.30**	.00
Science beliefs										
Intrinsic	.03	.24*	.36	.27*	.49**	-.20	-.13	-.09	.21	.03
Utility	.20	.16	.29	.23*	.38**	-.01	-.09	-.04	.24*	.07
Attainment	.15	.18	.35	.24*	.37**	-.30**	-.20	.04	.27*	.16
Difficulty	.06	.11	-.20	-.26*	-.33**	-.11	.03	.13	.07	.23*
Entity	.02	.12	-.14	-.11	-.18*	-.11	-.06	.07	-.04	.14

Listwise N = 76; * $p < .05$; ** $p < .01$

Table 37: Student curiosity correlations with classroom instruction and teacher beliefs

	Instruction					Mathematics/Science Beliefs				
	Academic challenge	Teacher enthusiasm	Data literacy	Inquiry learning	Teacher-directed learning	Intrinsic	Utility	Attainment	Difficulty	Entity
Mathematics (Listwise N = 80)										
Curiosity	.68**	.42**	.41**	.30**	.20	.41**	.16	.28*	-.28*	-.14
Science (Listwise N = 76)										
Curiosity	.61**	.37**	.39**	.30**	.39**	.23*	.05	.08	-.24*	-.15

* $p < .05$; ** $p < .05$.

DESIGN & TECHNOLOGY, DIGITAL TECHNOLOGY, AND INTEGRATED STEM TEACHER SURVEY RESULTS

Attitudes in design & technology, digital technology, and integrated STEM

Attitudes towards design & technology, digital technology, and integrated STEM are reported in Tables 38, 39 and 40, respectively, across the whole sample, and per state.

Overall, teachers reported high intrinsic value, high utility value, and moderate attainment value in design & technology, digital technology, and integrated STEM, indicating that they personally felt that all three subjects are valuable. They also reported that they found all three subjects to be somewhat difficult, with average scores around the midpoint.

Table 38: Attitudes (design & technology)

	Whole sample ***M* (SD)**
	n = 21
Intrinsic value[a]	5.70 (1.30)
Utility value[a]	6.18 (1.15)
Attainment value[a]	5.11 (1.38)
Difficulty[a]	4.08 (1.17)

[a] 1: Not at all, 7: Extremely

Table 39: Attitudes (digital technology)

	Whole sample ***M* (SD)**
	n = 18
Intrinsic value[a]	4.85 (1.30)
Utility value[a]	6.04 (1.15)
Attainment value[a]	4.45 (1.73)
Difficulty[a]	3.63 (1.40)

[a] 1: Not at all, 7: Extremely

Table 40: Attitudes (integrated STEM)

	Whole sample ***M* (SD)**
	n = 72
Intrinsic value[a]	5.78 (1.06)
Utility value[a]	5.94 (1.09)
Attainment value[a]	5.33 (1.22)
Difficulty[a]	3.91 (1.20)

[a] 1: Not at all, 7: Extremely

Instruction in design & technology, digital technology, and integrated STEM

Instruction in design & technology, digital technology, and integrated STEM are reported in Tables 41, 42 and 43, respectively. Overall, teachers reported that their students were not very curious in design and technology, digital technology, and integrated STEM. Teachers provided moderate levels of academic challenge in all three subjects and were highly enthusiastic in their teaching.

Data literacy practices occurred in "some lessons" for all three subjects. Inquiry learning practices occurred in 'some lessons' for design and technology, and digital technology, and between "some" and "many lessons" in integrated STEM. Teacher-directed instruction occurred in "many lessons" in the classrooms for all three subjects.

Table 41: Instruction (design & technology)

	Whole sample ***M* (SD)**
	n = 21
Curiosity[a]	4.02 (0.66)
Academic challenge[a]	4.12 (0.57)
Teacher enthusiasm[b]	5.67 (0.71)
Data literacy[c]	1.85 (0.60)
Inquiry learning[c]	2.37 (0.57)
Teacher-directed learning[c]	3.06 (0.52)

[a] 1: Strongly agree, 7: Strongly disagree; [b] 1: Not at all, 7: Completely
[c] 1: Never or almost never, 2: Some lessons, 3: Many lessons, 4: Every lesson or almost every lesson.

Table 42: Instruction (digital technology)

	Whole sample *M* (SD)
	n = 18
Curiosity[a]	3.75 (0.65)
Academic challenge[a]	3.78 (0.66)
Teacher enthusiasm[b]	5.30 (1.21)
Data literacy[c]	2.00 (0.46)
Inquiry learning[c]	2.26 (0.48)
Teacher-directed learning[c]	2.92 (0.69)

[a] 1: Strongly agree, 7: Strongly disagree
[b] 1: Not at all, 7: Completely
[c] 1: Never or almost never, 2: Some lessons, 3: Many lessons, 4: Every lesson or almost every lesson.

Table 43: Instruction (integrated STEM)

	Whole sample *M* (SD)
	n = 73
Curiosity[a]	4.11 (0.59)
Academic challenge[a]	4.24 (0.62)
Teacher enthusiasm[b]	6.13 (0.95)
Data literacy[c]	2.34 (0.62)
Inquiry learning[c]	2.67 (0.57)
Teacher-directed learning[c]	3.08 (0.62)

[a] 1: Strongly agree, 7: Strongly disagree
[b] 1: Not at all, 7: Completely
[c] 1: Never or almost never, 2: Some lessons, 3: Many lessons, 4: Every lesson or almost every lesson.

School culture

Descriptive statistics of school culture are reported in Table 44, across the whole sample.

Teachers reported positively about the leadership in their school, with means slightly above the midpoint on principal support. There was some level of reported pressure from principals placed on teachers, but this was consistently below the midpoint.

Teachers also displayed moderate self-efficacy beliefs regarding their own teaching abilities, and similarly for their colleagues' teaching abilities. Teachers felt moderately confident in collaborating with external sources (for example, universities, parents).

Finally, teachers demonstrated positive goal orientations. Mastery and relational goals were above the midpoint, while negative 'work avoidance' goals were low rated.

Table 44: School culture descriptives

	Whole sample ***N* = 106** ***M* (SD)**
School leadership	
Principal support[a]	4.11 (0.85)
Principal pressure[a]	2.51 (0.86)
Efficacy beliefs	
Self-efficacy[c]	3.23 (0.44)
External engagement[b]	4.44 (1.40)
Collective efficacy – group competence[a]	5.15 (0.83)
Collective efficacy – task analysis[a]	4.73 (0.80)
Goals	
Relational[a]	4.13 (0.70)
Mastery approach[a]	4.28 (0.54)
Work avoidance[a]	2.28 (0.77)

[a] 1: Strongly disagree, 5: Strongly agree
[b] 1: Not at all confident, 7: Extremely confident
[c] 1: Not at all, 2: To some extent, 3: Quite a bit, 4: A lot.

Relationships among school culture and teachers' classroom practices

To examine the extent of relationship between teachers' classroom practices/beliefs and school culture, Pearson correlations were computed between these factors (see Tables 45, 46, 47 and 48). Asterisked relationships indicate those which were statistically significant, summarised below. Correlations can range from 0 (no relationship) to ±1 (perfect correspondence); positive numbers indicate a same direction of relationship and negative numbers the opposite. Interpreted correlations below are those statistically significant at $p < .05$.

DESIGN & TECHNOLOGY TEACHERS:

- There were essentially no associations.

DIGITAL TECHNOLOGY TEACHERS:

- There were essentially no associations.

INTEGRATED STEM TEACHERS:

- Teachers' external engagement strongly promoted teaching practices involving data literacy and inquiry learning.

Relationships among teachers' efficacy beliefs and goals, with classroom practices and beliefs about design & technology/digital technology/integrated STEM

DESIGN & TECHNOLOGY:

- Teachers' self-efficacy regarding their own teaching abilities was highly positively related to teacher-directed learning.
- Beliefs about colleagues' teaching abilities ("Group competence") had a strong negative relationship with teachers use of teacher-directed learning.
- Teachers' relational goals to develop caring relationships with students, were negatively correlated with providing academic challenge.
- Mastery goals, to improve their own instruction, related to strongly to teaching enthusiasm.

DIGITAL TECHNOLOGY:

- Work avoidance goals were negatively associated with teacher-directed learning.

INTEGRATED STEM:

- Teachers' self-efficacy regarding their own teaching abilities were negatively associated with belief that the subject was difficult.
- Individual teacher efficacy was associated strongly with academic challenge, teaching enthusiasm, data literacy and inquiry learning.
- Beliefs about colleagues' teaching abilities ("Group competence") was strongly negatively related to belief that STEM is difficult.
- Mastery goals, to improve their own instruction, related to academic challenge and teaching enthusiasm.
- Mastery goals, to improve their own instruction, were strongly related to belief in the value and usefulness of integrated STEM.

Relationships with student outcomes

DESIGN & TECHNOLOGY:

- None of the measured instructional practices were associated with promoting student curiosity.

DIGITAL TECHNOLOGY:

- The level of academic challenge, and belief that the subject was difficult were associated with promotion of student curiosity.

INTEGRATED STEM:

- Students' curiosity was dampened by both academic challenge and teacher enthusiasm,
- Neither teacher-directed instruction not inquiry learning benefited student curiosity.
- Teachers' own level of interest (intrinsic value) promoted students' curiosity in integrated STEM; teachers who perceived STEM to be more difficult dampened students' curiosity.

Table 45: Design & technology correlations with school climate

	School leadership			Efficacy beliefs			Goals		
	Principal support	Principal pressure	External engagement	Self-efficacy	Collective efficacy – Group competence	Collective efficacy – Task analysis	Relational	Mastery	Work avoidance
Instruction									
Academic challenge	-.65	.41	.17	-.19	-.86	-.07	-.95*	.14	-.79
Teacher enthusiasm	.14	-.71	.45	.71	.22	-.78	-.26	.997*	.43
Data literacy	.94	-.79	.86	.89	.69	-.82	.59	.98	.33
Inquiry learning	.27	-.69	.73	.81	.15	-.92	-.26	.93	.14
Teacher-directed learning	.71	-.90	.86	.99**	.55	-.99**	.24	.98	.33
Design & technology beliefs									
Intrinsic	-.14	-.34	.53	.49	-.26	-.68	-.64	.81	-.10
Utility	-.08	-.41	.56	.55	-.19	-.72	-.58	.85	-.03
Attainment	.22	-.59	.78	.76	.03	-.89	-.34	.86	-.02
Difficulty	-.70	.98*	-.68	-.98*	-.69	.93	-.32	-.99	-.60

Listwise N = 21; * $p < .05$; ** $p < .01$

Table 46: Digital technology correlations with school climate

	School leadership			Efficacy beliefs			Goals		
	Principal support	Principal pressure	External engagement	Self-efficacy	Collective efficacy – Group competence	Collective efficacy – Task analysis	Relational	Mastery	Work avoidance
Instruction									
Academic challenge	.38	.42	.03	.55	-.53	-.23	.60	.38	.02
Teacher enthusiasm	-.07	-.19	.54	.41	-.50	.23	-.23	-.45	.15
Data literacy	.20	.000	-.03	-.26	.08	.36	-.14	.18	-.13
Inquiry learning	.12	.12	.32	.36	-.08	.27	.27	.04	-.43
Teacher-directed learning	-.59	.15	.27	.35	.39	.23	-.26	-.36	-.81*
Digital technology beliefs									
Intrinsic	.27	-.39	.14	.40	-.85**	-.30	-.07	-.09	.44
Utility	.00	.19	-.23	.14	-.12	-.04	-.22	.14	-.49
Attainment	.16	-.50	.53	.45	-.65	-.003	.12	-.37	.30
Difficulty	.13	.56	-.66	-.08	.08	-.28	.03	.59	-.38

Listwise N = 18; * $p < .05$; ** $p < .01$

Table 47: Integrated STEM correlations with school climate

	School leadership			Efficacy beliefs			Goals		
	Principal support	Principal pressure	External engagement	Self-efficacy	Collective efficacy – Group competence	Collective efficacy – Task analysis	Relational	Mastery	Work avoidance
Instruction									
Academic challenge	.07	.06	.23	.71**	.29	.39	-.07	.50*	-.33
Teacher enthusiasm	.15	-.06	.43	.78**	.27	.41	-.11	.47*	-.39
Data literacy	.22	.04	.67**	.46*	.16	.35	-.16	-.44	-.01
Inquiry learning	.06	.13	.72**	.64**	.05	.29	-.21	-.16	-.05
Teacher-directed learning	-.14	.08	.38	.40	.08	.30	.08	-.05	.15
Integrated STEM beliefs									
Intrinsic	.08	-.07	.12	.60**	.31	.16	-.18	.72**	-.32
Utility	.19	-.06	.11	.64**	.33	.29	-.19	.62**	-.26
Attainment	.12	.09	.32	.06	.05	.18	-.41	-.09	.05
Difficulty	.14	.04	-.21	-.58**	-.37	-.63**	-.34	.05	.28

Listwise N = 74; * $p < .05$; ** $p < .01$

Table 48: Student curiosity correlations with classroom instruction and teacher beliefs

	Instruction					Design & technology/digital technology/integrated STEM beliefs			
	Academic challenge	Teacher enthusiasm	Data literacy	Inquiry learning	Teacher-directed learning	Intrinsic	Utility	Attainment	Difficulty
Design & technology (Listwise *N* = 21)									
Curiosity	.87	-.08	-.15	.17	-.09	.45	.39	.33	.35
Digital technology (Listwise *N* = 18)									
Curiosity	.79*	-.12	.000	.60	.49	-.31	.56	-.32	.76*
Integrated STEM (Listwise *N* = 74)									
Curiosity	-.81**	-.71**	.22	.32	.26	.67**	.72**	.32	-.48*

* $p < .05$; ** $p < .05$.

A.5 Student Survey: Description of Measures

The survey gathered as much data as practicable on a diversity of areas concerned with students' perceptions related to STEM and STEM teaching and learning and STEM-related career aspirations and 21st Century skills.

Measurement properties were acceptable in terms of the reliabilities for all constructs (Cronbach's measure of internal consistency is reported in descriptive results tables, per STEM domain) except where highlighted below for psychological cost (in mathematics and science) and use of materials/tools (in mathematics, science, digital technologies, and primary school technology).

(I) PERCEIVED SOCIALISER BELIEFS AND STUDENT ENGAGEMENT DIMENSIONS

Perceived Socialiser Beliefs (mathematics / science)

Sex typing items (Watt, 2002) tapped student beliefs about whether girls or boys are better at mathematics / science (2 items: e.g., "Do you think boys or girls are better at maths?). Items were rated on a 7-point Likert scale, ranging from 1 *(boys better)*, 4 *(equally)*, 7 *(girls better)*.

Peer value (adapted by Watt, 2002 from Eccles & Wigfield, 1995) measured how students thought their friends perceived mathematics / science (4 items: e.g., "My friends find working on maths…"), rated on a 7-point Likert scale for example from 1 *(Very boring)* to 7 *(Very interesting)*.

Theory of intelligence (mathematics / science)

Theory of intelligence items (adapted from Dweck et al., 1995) measured the extent to which students believed their abilities in mathematics / science were fixed ("entity" belief), rather than malleable ("incremental" or growth belief) (3 items: e.g., "You have a certain amount of ability in maths and can't do much to change it"). All items were rated on a 6-point Likert scale ranging from 1 *(Strongly disagree)* to 6 *(Strongly agree)*.

Motivations

Motivational constructs from Eccles and Wigfield (1995; adapted to the Australian context by Watt, 2002, 2004) were used to assess motivations at school:

- perceived talent (3 items: e.g., how students perceived their talent compared with other students);
- instrumental value (3 items: e.g., if students felt the subjects would help with getting a job);
- attainment value (3 items: e.g., if being good at the subjects was important to who they are);
- intrinsic value (single item, how interesting they find the subjects).

All items were rated on a 7-point Likert scale ranging from 1 *(Not at all)* to 7 *(Extremely)*.

Costs

A multidimensional measure of cost assessed the demands felt by students studying each STEM domain, comprising:

- effort cost (3 items: e.g., "When I think about the hard work needed to get through in mathematics, I am sure that it is going to be worth it in the end"; Watt, Bucich, & Dacosta, 2019);
- psychological cost (2 items: e.g., "I'm concerned that I won't be able to handle the stress that goes along with studying maths"; Watt, Bucich, & Dacosta, 2019); and
- difficulty (3 items: e.g., "To what extent do you consider maths to be a tough subject?"; Watt, 2002).

All items were rated on a 7-point Likert scale ranging from 1 *(Not at all)* to 7 *(Extremely)*. Measures of internal consistency were poor for psychological cost in mathematics and science, but are still reported as part of the results although a high degree of measurement error is attached in those instances.

Effort exertion

Two items measured the amount of effort students put into their STEM subjects (Watt, 2002; e.g., "How much effort do you put into mathematics?"). Items were rated on a 7-point scale from 1 *(Not at all)* to 7 *(Extremely)*.

Achievement goals

Achievement goals (Midgley et al., 2000) assessed students' reasons for wanting to achieve in each STEM domain:

- Mastery goal (3 items: e.g., "One of my goals in maths is to learn as much as I can");
- Performance-approach goal (3 items: e.g., "One of my goals is to show others that I am good at maths"); and
- Performance-avoidance goal (3 items: e.g., "It's important that I don't look stupid in maths lessons").

All items were rated on a 7-point Likert scale ranging from 1 (Not at all true) to 5 (Very true).

(II) STUDENT-PERCEIVED CLASSROOM AND TEACHER FACTORS

Learning environment

Learning environment was assessed on five key dimensions per STEM domain.

Classroom climate (Midgley et al., 1996) measures included mastery climate (3 items: e.g., "Our maths teacher really wants us to enjoy learning new things"), and performance climate (3 items: e.g., "Our maths teacher tells us how we compare to other students"), rated on a 7-point scale from 1 (Not at all) to 7 (Extremely). A "Mastery climate" refers to a classroom in which the teacher promotes mastery and understanding of learning. This is in contrast to a

"Performance climate" in which teachers emphasise competition and achievement comparisons between students. However, it is possible for teachers to adopt both dimensions to varying degrees. In general, mastery climates best promote students' interest and engagement.

Teacher enthusiasm was adapted from Kunter et al. (2011) whose scale was developed for teachers to report their own enthusiasm. We adapted their items to measure students' perception of teachers' enthusiasm (3 items: e.g., "Our maths teacher teaches maths with great enthusiasm"). Items were rated on a 7-point Likert scale ranging from 1 (Not at all) to 7 (Extremely).

Academic challenge items were especially developed for PASL (inspired by Pascarella, Edison, Nora, Hagedorn, & Terenzini, 1996) using 3 items (e.g., "My mathematics class makes me think about mathematics from different perspectives"), rated on a 5-point Likert scale ranging from 1 (Strongly disagree) to 5 (Strongly agree).

Curiosity about each STEM subject was assessed by 2 items targeting cognitive interest from the six-item interest scale of Frenzel et al. (2012; e.g., "I would like to find out much more about some of the things we deal with in our maths class"). Items were rated on a 5-point Likert scale ranging from 1 (Strongly disagree) to 5 (Strongly agree).

Classroom practice

Classroom practice was measured using three sets of factors from various sources.

Teacher practice (from OECD, 2016b) encompassed three factors – beginning with the stem "How often do these things happen in your school maths lesson?":

- inquiry learning (4 items: e.g., "I am asked to draw conclusions from mathematical enquiries I have conducted");
- teacher-directed learning (4 items: e.g., "My teacher discusses questions that students ask");
- teacher support (4 items: e.g., "The teacher gives extra help when students need it").

Items were rated on a 4-point scale from 1 (Never or almost never), 2 (Some lessons), 3 (Many lessons), to 4 (Every lesson or almost every lesson).

Data literacy items (especially developed for PASL, inspired by Anderson et al., 2010) were used to measure how students used data in their regular lessons, in response to the stem "How often do these things happen in your school?" (4 items: e.g., "I evaluate the quality of data to develop my understanding"). Items were rated on a 4-point scale from 1 (Never or almost never), 2 (Some lessons), 3 (Many lessons), to 4 (Every lesson or almost every lesson).

Items tapping the use of equipment in mathematics (developed by the PASL directors, based on Gulek, 1999) assessed two factors, in response to the stem "How often do you use each of the following?":

- materials/tools: 3 items; e.g., "Use of electrical equipment (e.g., computers, design programmes, robotic kits, calculators)"; and
- representational tools: 3 items; e.g., "Creates tables, graphs and diagrams".

Items were rated on a 7-point scale from 1 (Not at all) to 7 (Every lesson).

Measures of internal consistency were poor for use of materials/tools (in mathematics, science, digital technologies, and primary school technology), but are still reported as part of the results although a high degree of measurement error is attached in those instances.

Student-perceived teacher beliefs

Four dimensions of how students perceived their teachers' beliefs were assessed:

- expectation (2 items: e.g., "How talented does your teacher think you are at mathematics?");
- difficulty (2 items: e.g., "How difficult does your teacher think you find mathematics?);
- value (2 items: e.g., "How useful does your teacher think mathematics is?"); and
- relationship (2 items: e.g., "How well do you and your mathematics teacher relate to each other?).

All items were rated on a 7-point scale from 1 (Not at all) to 7 (Extremely).

(III) CAREER ASPIRATIONS AND 21ST CENTURY SKILLS

Career Aspirations

The extent to which secondary school students would be interested to pursue each of several STEM-related careers was assessed by the question "How much would you like to have a <subject>-related career?", rated 1 (Not at all) to 7 (Extremely).

21st Century Skills

The extent to which students felt confident that they had developed skills suited for life in the 21st Century were assessed using items adapted from the 21st Century Skills scale (Jia et al., 2016). Target skills include collaboration, communication, being a responsible citizen, problem solving, innovation and creativity. Students were asked to respond to 11 statements prefaced by the stem "How confident are you in each of the following?" (e.g., "Collaborating with peers to achieve a goal on a STEM project"). Each of the 11 items was adapted to mention the STEM learning context. All items were rated on a 7-point Likert scale from 1 (Not at all confident) to 7 (Completely confident).

A.6 Student Survey: Descriptive Statistics and Correlations

Results: Mathematics

Perceived Socialiser Beliefs, Motivations, Costs and Achievement Goals

Table 49 shows descriptive statistics for students in each grade band.

- For sex-typing of mathematics, mean scores were close to the midpoint, indicating a perception of boys being slightly better at mathematics.
- Students perceived their peers to display rather neutral interest in mathematics, indicated by mean scores below the scale midpoint, especially in secondary school.
- On average, students tended to hold an incremental (rather than a fixed or entity) view about their mathematical abilities, believing they could grow and improve.
- Motivational factors (perceptions of own mathematical talent, instrumental, attainment and intrinsic values) were rated above or close to the scale midpoint, indicating that students were generally positively motivated. There was a pattern whereby primary students indicated more positive mathematics motivations than secondary students.
- For negative costs, mean scores varied around the midpoint indicating that mathematics was experienced as moderately difficult, provoking moderate levels of effort cost and being somewhat psychologically taxing. This was more so for older students.
- Effort exerted scores were above the midpoint, indicating moderate effort investment in mathematics.
- Mastery goals were more strongly endorsed than performance goals for learning mathematics, and more so by primary than secondary students.

Table 49: Student-Perceived Socialiser Beliefs, Motivations, Costs and Achievement Goals in Mathematics

Mathematics	**Whole Sample**		
	Primary Y4-6 M (SD)	**Lower secondary Y7-8 *M* (SD)**	**Mid secondary Y9-10 *M* (SD)**
Perceived socialiser beliefs	*n* = 404	*n* = 340	*n* = 221
[a]Sex typing (α = .67)	3.92 (0.94)	3.94 (0.95)	3.75 (1.13)
[b]Peer value (α = .82)	3.89 (1.37)	3.31 (1.38)	3.24 (1.30)
[c]*Theory of intelligence* (α = .81)	2.79 (1.32)	2.76 (1.28)	2.60 (1.24)
[d]*Motivations*	*n* = 391	*n* = 318	*n* = 217
Perceived talent (α = .79)	4.58 (1.56)	4.48 (1.68)	4.26 (1.64)
Instrumental value (α = .81)	5.66 (1.61)	4.98 (1.78)	4.92 (1.86)
Attainment value (α = .88)	4.74 (1.85)	4.55 (1.71)	4.43 (1.74)
Intrinsic value	4.78 (1.86)	4.13 (1.83)	4.03 (1.80)
[d]*Costs*	*n* = 391	*n* = 318	*n* = 217
Difficulty (α = .70)	3.29 (1.46)	3.87 (1.61)	4.05 (1.53)
Effort cost (α = .93)	3.14 (1.71)	3.59 (1.80)	4.06 (1.76)
Psychological cost (α = .39)	2.69 (1.80)	3.10 (1.79)	3.25 (1.89)
[d] *Effort exerted* (α = .93)	n/a	4.70 (1.70)	4.71 (1.55)
[e]*Achievement goals*	*n* = 179	*n* = 90	*n* = 146
Mastery (α = .91)	4.20 (0.76)	3.54 (1.21)	3.53 (1.13)
Perf.-approach (α = .90)	3.01 (1.08)	2.81 (1.25)	2.87 (1.21)
Perf.-avoidance (α = .84)	3.14 (1.03)	2.88 (1.13)	2.89 (1.16)

[a] 1: boys better, 4: equally, 7: girls better; [b] 1: not at all, 7: very; [c] 1: strongly disagree, 6: strongly agree; [d] 1: not at all, 7: extremely; [e] 1: not at all true, 3: somewhat true, 5: very true

Student-Perceived Mathematics Classroom and Teacher Factors

Table 50 shows descriptive statistics for students in each grade band.

- Mathematics classroom climate appeared more positive for younger than older students. A mastery climate was more pronounced for primary school students, whereas a more performance-oriented climate was experienced more by secondary school students. A similar pattern was evident for teacher enthusiasm, perceived more positively by younger than older students; although, still moderately positively perceived among secondary students.
  Secondary school students were asked about cognitive classroom dimensions of academic challenge and promoting curiosity. Academic challenge was rated at the scale midpoint and curiosity was lower than the scale midpoint, indicating that on average, students did not experience much challenge or especially curiosity in their mathematics classrooms.

- Dimensions of classroom practice (inquiry learning, teacher-directed learning, teacher support) were each rated between 2 (some lessons) and 3 (many lessons). The same was true for use of materials/tools, and representational tools.
- Student-perceived teacher beliefs revealed that students believed their teachers held positive expectations that they could succeed in mathematics at the same time as thinking that students found mathematics moderately difficult.
  Students perceived that their teachers believed mathematics to be of high value.
  In general, students experienced positive relationships with their mathematics teachers; more so for primary than secondary school students.

Table 50: Student-Perceived Classroom and Teacher Factors in Mathematics

Mathematics	**Whole Sample**		
	Primary Y4-6 *M* (SD)	**Lower secondary Y7-8 *M* (SD)**	**Mid secondary Y9-10 *M* (SD)**
Learning environment	*n* = 184	*n* = 84	*n* = 143
[a]Mastery climate (α = .92)	5.68 (1.31)	3.48 (1.22)	3.55 (1.14)
[a]Performance climate (α = .80)	3.79 (1.71)	4.29 (1.77)	4.07 (1.72)
[a]Teacher enthusiasm (α = .96)	5.43 (1.35)	5.04 (1.68)	4.91 (1.90)
[b]Academic challenge (α = .89)	n/a	3.18 (1.10)	3.10 (1.06)
[b]Curiosity (α = .83)	n/a	2.86 (1.24)	2.89 (1.14)
Classroom practice	*n* = 184	*n* = 91	*n* = 150
[c]Inquiry learning (α = .75)	n/a	2.39 (0.73)	2.33 (0.73)
[c]Teacher-directed (α = .90)	n/a	2.84 (0.87)	2.91 (0.85)
[c]Teacher support (α = .95)	n/a	2.90 (0.85)	3.04 (0.92)
[c]Data literacy (α = .88)	n/a	2.56 (0.82)	2.58 (0.80)
[d]Use of materials/tools (α = .49)	2.62 (0.69)	2.57 (0.74)	2.48 (0.86)
[d]Representational tools (α = .86)	2.43 (0.60)	2.50 (0.78)	2.39 (0.79)
[a]*Student-perceived teacher beliefs*	*n* = 182	*n* = 91	*n* = 150
Expectation (α = .89)	5.17 (1.19)	4.60 (1.80)	4.66 (1.55)
Difficulty (α = .61)	4.04 (1.33)	4.43 (1.53)	4.35 (1.40)
Value (α = .87)	5.46 (1.13)	5.18 (1.79)	5.21 (1.68)
Relationship (α = .87)	4.84 (1.43)	4.25 (1.78)	4.40 (1.69)

[a] 1: not at all, 7: extremely
[b] 1: strongly disagree, 5: strongly agree
[c] 1: never or almost never, 2: some lessons, 3: many lessons, 4: almost every lesson or every lesson
[d] 1: not at all, 7: every lesson

To examine the extent of relationship between the two sets of mathematics factors, Pearson correlations were computed between student-perceived socialiser beliefs, motivations, costs and achievement goals; and student-perceived classroom and teacher factors (see Table 51). Asterisked relationships indicate those which were statistically significant.

Correlations can range in strength from 0 (no relationship) to ±1 (perfect correspondence); positive numbers indicate a same direction of relationship and negative numbers the opposite. Stronger correlations $r \geq .50$ (that is, 25% shared variance) have been underlined for emphasis and summarised below.

Students' motivations (perceived talent and different kinds of values) in mathematics, their effort exertion and own mastery goals for learning were the aspects of student engagement that appeared most responsive to their classroom environments and teacher factors.

- Learning environment dimensions of mastery climate, teacher enthusiasm, academic challenge and promoting curiosity strongly related to students' mathematics motivations, effort exertion and own mastery goals for learning.
- In contrast, learning environments characterised by a performance climate associated more than mastery climate, with the negative student engagement factors we had measured (that is, fixed theory of intelligence, costs, and performance-avoidance goals).
- Teacher-directed learning and teacher support showed stronger associations with students' positive motivations, efforts and mastery goals than inquiry learning. Data literacy activities also proved beneficial; use of materials and representational tools less so.
- Student-perceived teacher beliefs strongly related to students' mathematics motivations, effort exertion and own mastery goals for learning, even the perception that their teacher thought they found mathematics difficult. Presumably when a teacher's response is to provide support within the context of a positive relationship, this is not detrimental.

Table 51: Correlations of Student-Perceived Socialiser Beliefs, Motivations, Costs and Achievement Goals with Student-Perceived Classroom and Teacher Factors in Mathematics (Listwise N = 237)

	Soc. beliefs		Entity	Motivations				Costs			Effort	Achievement goals		
	Sex-typing	Peer value	Theory of intelligence	Perceived talent	Instrumental value	Attainment value	Intrinsic value	Difficulty	Effort cost	Psychological cost	Effort exerted	Mastery goals	Perf. approach goals	Perf. avoidance goals
Learning environment														
Mastery climate	.16*	.31*	-.03	.44*	.57*	.51*	.51*	.40*	.22*	.15**	.59*	.59*	.34*	.37*
Performance climate	.13**	.31*	.14**	.37*	.43*	.43*	.41*	.39*	.26*	.24*	.47*	.42*	.49*	.45*
Teacher enthusiasm	.15**	.30*	-.02	.41*	.56*	.49*	.52*	.43*	.25*	.18*	.59*	.58*	.36*	.37*
Academic challenge	.13**	.44*	-.02	.51*	.67*	.64*	.59*	.34*	.21*	.01	.64*	.67*	.39*	.42*
Curiosity	.10	.46*	.04	.46*	.63*	.63*	.52*	.31*	.17*	-.04	.56*	.60*	.43*	.43*
Classroom practice														
Inquiry learning	.09	.31*	.13**	.37*	.45*	.43*	.38*	.41*	.28*	.17*	.51*	.41*	.47*	.45*
Teacher-directed	.15**	.27*	-.02	.42*	.54*	.46*	.49*	.40*	.22*	.15**	.56*	.57*	.29*	.32*
Teacher support	.19*	.26*	-.09	.42*	.56*	.44*	.52*	.35*	.16*	.08	.56*	.60*	.28*	.31*
Data literacy	.12	.28*	.06	.40*	.56*	.48*	.50*	.45*	.24*	.13**	.57*	.55*	.45*	.46*
Use of material/tools	.14**	.18*	.13**	.33*	.34*	.27*	.35*	.29*	.21*	.18*	.35*	.36*	.25*	.26*
Representational tools	.19*	.14**	.05	.27*	.41*	.34*	.40*	.39*	.27*	.22*	.35*	.30*	.28*	.29*
Student-perceived teacher beliefs														
Expectation	.10	.33*	.12	.66*	.62*	.59*	.58*	.35*	.30*	.12**	.59*	.67*	.36*	.37*
Difficulty	.20*	.21*	.18*	.41*	.48*	.48*	.45*	.61*	.43*	.34*	.50*	.49*	.39*	.42*
Value	.18*	.22*	.04	.55*	.61*	.52*	.57*	.45*	.29*	.18*	.59*	.66*	.34*	.39*
Relationship	.13**	.34*	.09	.52*	.57*	.53*	.54*	.43*	.30*	.20*	.55*	.55*	.41*	.40*

* $p < .05$, ** $p < .01$

Results: Science

Perceived Socialiser Beliefs, Motivations, Costs and Achievement Goals

Table 52 shows descriptive statistics for students in each grade band.

- For sex-typing of mathematics, mean scores were all below the midpoint, indicating perceptions that boys were better at science. Primary school students thought their peers were quite interested in science; secondary students were more neutral.
- Students tended to hold an incremental view, over a fixed one, about their abilities in science, believing they could grow and improve.
- Motivational factors (perceptions of own scientific talent, instrumental, attainment and intrinsic values) were rated above the midpoint, indicating that students were positively motivated in science. Primary school students were more motivated than secondary students.
- Negative costs were more pronounced for secondary students, indicating they experienced science as moderately difficult, provoking moderate levels of effort cost, and as somewhat psychologically taxing.
- Effort exertion indicated moderate investment in science.
- Mastery goals were more strongly endorsed than performance goals in learning science, especially for primary school students.

Table 52: Student-Perceived Socialiser Beliefs, Motivations, Costs and Achievement Goals in Science

SCIENCE	WHOLE SAMPLE		
	Primary Y4-6 *M* (SD)	**Lower secondary Y7-8 *M* (SD)**	**Mid secondary Y9-10 *M* (SD)**
Perceived socialiser beliefs	*n* = 404	*n* = 338	*n* = 222
[a]Sex typing (α = .70)	3.92 (0.83)	3.79 (0.90)	3.66 (0.99)
[b]Peer value (α = .86)	4.79 (1.14)	3.92 (1.56)	3.62 (1.36)
[c]***Theory of intelligence***	2.65 (1.28)	2.66 (1.34)	2.53 (1.36)
[d]***Motivations***	*n* = 382	*n* = 320	*n* = 211
Perceived talent (α = .76)	4.52 (1.44)	4.31 (1.57)	4.09 (1.71)
Instrumental value (α = .89)	4.82 (1.91)	4.14 (1.99)	4.35 (1.88)
Attainment value (α = .88)	4.36 (1.89)	4.15 (1.83)	4.17 (1.89)
Intrinsic value	5.29 (1.71)	4.57 (1.90)	4.36 (1.89)
[d]*Costs*	*n* = 382	*n* = 320	*n* = 211
Difficulty (α = .73)	3.37 (1.47)	3.81 (1.61)	4.09 (1.69)
Effort cost (α = .92)	2.78 (1.60)	3.20 (1.69)	3.90 (1.88)
Psychological cost (α = .43)	2.94 (1.85)	3.27 (1.80)	3.31 (1.91)
[d]***Effort exerted*** (α = .92)	n/a	4.66 (1.52)	4.40 (1.64)
[e]***Achievement goals***	*n* = 178	*n* = 96	*n* = 121
Mastery (α = .91)	3.83 (0.97)	3.54 (1.04)	3.34 (1.16)
Perf.-approach (α = .92)	2.83 (1.18)	2.98 (1.15)	2.84 (1.22)
Perf.-avoidance (α = .88)	3.05 (1.13)	3.09 (1.06)	2.98 (1.17)

[a] 1: boys better, 4: equally, 7: girls better; [b] 1: not at all, 7: very; [c] 1: strongly disagree, 6: strongly agree; [d] 1: not at all, 7: extremely; [e] 1: not at all true, 3: somewhat true, 5: very true

Student-Perceived Science Classroom and Teacher Factors

Table 53 shows descriptive statistics for students in each grade band.

- Classroom climate appeared positive overall.
  - A mastery climate was prevalent in both primary and secondary, but performance-oriented climates became more apparent in secondary school.
  - A similar pattern was evident for teacher enthusiasm, perceived positively by students at all grade bands, but more so by primary students.
  - The cognitive dimension of academic challenge for secondary students was only at the scale midpoint. For promoting curiosity, mean scores for lower secondary students were similarly at the midpoint, but were lower among mid secondary students.
- Dimensions of classroom practice (inquiry learning, teacher-directed learning, teacher support and data literacy) were each rated between 2 (some lessons) and 3 (many lessons).
  - Use of materials/tools and representational tools were low endorsed, with mean scores well below the scale midpoint.
- Student-perceived teacher beliefs were mostly above the midpoint, indicating that students believed their teacher held positive expectations that they could succeed in science while also perceiving science to be moderately difficult.
  - Students perceived that their teachers believed science was of high value.
  - In general, students experienced positive relationships with their science teachers, especially for younger students.

Table 53: Student-Perceived Classroom and Teacher Factors in Science

Science	Whole Sample		
	Primary Y4-6 *M* (SD)	**Lower secondary Y7-8 *M* (SD)**	**Mid secondary Y9-10 *M* (SD)**
Learning environment	***n* = 183**	***n* = 95**	***n* = 125**
[a]Mastery climate (α = .89)	5.69 (1.25)	4.79 (1.61)	4.61 (1.89)
[a]Performance climate (α = .80)	3.49 (1.82)	3.79 (1.75)	3.99 (1.92)
[a]Teacher enthusiasm (α = .91)	5.35 (1.34)	4.91 (1.72)	4.72 (1.89)
[b]Academic challenge (α = .82)	n/a	3.22 (1.04)	3.04 (1.22)
[b]Curiosity (α = .86)	n/a	3.26 (1.00)	2.96 (1.25)
Classroom practice	***n* = 185**	***n* = 97**	***n* = 123**
[c]Inquiry learning (α = .75)	n/a	2.46 (0.72)	2.41 (0.80)
[c]Teacher-directed (α = .90)	n/a	2.89 (0.72)	2.69 (0.89)
[c]Teacher support (α = .95)	n/a	2.94 (0.77)	2.80 (0.94)
[c]Data literacy (α = .88)	n/a	2.51 (0.71)	2.45 (0.83)
[d]Use of materials/tools (α = .47)	2.34 (0.72)	2.28 (0.74)	2.28 (0.81)
[d]Use of representational tools (α = .92)	2.40 (0.69)	2.45 (0.69)	2.31 (0.83)
[a]Student-perceived teacher beliefs	***n* = 181**	***n* = 97**	***n* = 123**
Expectation (α = .89)	4.94 (1.10)	4.52 (1.54)	4.44 (1.66)
Difficulty (α = .75)	4.23 (1.15)	4.12 (1.41)	4.24 (1.60)
Value (α = .91)	4.91 (1.15)	4.83 (1.60)	4.80 (1.75)
Relationship (α = .92)	4.49 (1.36)	4.01 (1.66)	4.15 (1.76)

[a] 1: not at all, 7: extremely
[b] 1: strongly disagree, 5: strongly agree
[c] 1: never or almost never, 2: some lessons, 3: many lessons, 4: almost every lesson or every lesson
[d] 1: not at all, 7: every lesson

Pearson correlations again measured the strength of relationships between the two sets of science factors: student-perceived socialiser beliefs, motivations, costs and achievement goals; and student-perceived classroom and teacher factors (see Table 54).

Asterisked relationships denote which were statistically significant.

Correlations can range in strength from 0 (no relationship) to ±1 (perfect correspondence); positive numbers indicate a same direction of relationship and negative numbers the opposite. Stronger correlations $r \geq .50$ (that is, 25% shared variance) have been underlined for emphasis and summarised below.

Students' motivations (perceived talent and different kinds of values) in mathematics, their effort exertion and own mastery goals for learning were the dimensions of student engagement that appeared most responsive to their classroom environments and teacher factors. There were also several strong relationships with students' perceptions of science being difficult and their performance goals.

- Mastery and performance science classroom goal climates were strongly positively correlated with students' science motivations, efforts exerted and own mastery goals; but correlations with mastery goal climates were more consistent. Performance goal climates also related more to negative student cost factors than did mastery climates.
- Learning environment dimensions of teacher enthusiasm, academic challenge and promoting curiosity strongly related to students' mathematics motivations, effort exertion and mastery goals for learning.
- Inquiry-based learning, teacher-directed learning and teacher support in science class showed similarly strong associations with students' motivations, efforts and mastery goals. Inquiry-based learning also showed strong associations with negative student factors: perceived difficulty and own performance-avoidance goals. Data literacy activities also proved beneficial; use of materials and representational tools, less so.
- Student-perceived teacher beliefs also strongly related to students' science motivations, effort exertion and own mastery goals for learning – even the perception that their teacher thought they found science difficult. Presumably when a teacher's response is to provide support within the context of a positive relationship, this is not detrimental.

Table 54: Correlations of Student-Perceived Socialiser Beliefs, Motivations, Costs and Achievement Goals with Student-Perceived Classroom and Teacher Factors in Science (Listwise N = 218)

	Soc. beliefs		Entity	Motivations				Costs			Effort	Achievement goals		
	Sex-typing	Peer value	Theory of intelligence	Perceived talent	Instrumental value	Attainment value	Intrinsic value	Difficulty	Effort cost	Psychological cost	Effort exerted	Mastery goals	Perf. approach goals	Perf. avoidance goals
Learning environment														
Mastery climate	.05	.40*	-.06	.53*	.65*	.61*	.62*	.43*	.18*	-.02	.65*	.68*	.44*	.47*
Performance climate	.04	.34*	.02	.41*	.48*	.49*	.46*	.51*	.27*	.14**	.49*	.46*	.54*	.48*
Teacher enthusiasm	.03	.42*	-.04	.54*	.63*	.60*	.60*	.43*	.15**	-.03	.65*	.66*	.46*	.50*
Academic challenge	.05	.45*	-.02	.68*	.68*	.69*	.65*	.42*	.18*	-.05	.68*	.67*	.49*	.53*
Curiosity	.02	.50*	-.05	.68*	.67*	.70*	.63*	.36*	.13**	-.08	.68*	.65*	.49*	.53*
Classroom practice														
Inquiry learning	.00	.30*	.05	.50*	.61*	.61*	.64*	.51*	.37*	.21*	.63*	.52*	.57*	.54*
Teacher-directed	.04	.30*	-.07	.51*	.60*	.55*	.60*	.44*	.23*	.08	.63*	.64*	.44*	.48*
Teacher support	.06	.42*	-.07	.55*	.60*	.58*	.57*	.40*	.17**	.00	.63*	.65*	.42*	.45*
Data literacy	.04	.34*	.00	.56*	.66*	.65*	.67*	.50*	.32*	.17*	.66*	.62*	.55*	.55*
Use of material/tools	-.02	.40*	.01	.41*	.44*	.45*	.43*	.44*	.24*	.10	.47*	.39*	.42*	.44*
Representational tools	.03	.30*	.03	.43*	.47*	.46*	.49*	.42*	.24*	.09	.48*	.45*	.39*	.39*
Student-perceived teacher beliefs														
Expectation	.01	.36*	-.04	.67*	.63*	.61*	.58*	.42*	.17**	.00	.66*	.64*	.45*	.52*
Difficulty	.02	.30*	.09	.45*	.50*	.48*	.50*	.64*	.35*	.21*	.64*	.56*	.45*	.52*
Value	.01	.26*	-.05	.55*	.60*	.58*	.56*	.45*	.18*	.03	.66*	.64*	.41*	.47*
Relationship	.03	.37*	.02	.64*	.64*	.62*	.64*	.46*	.26*	.06	.68*	.58*	.56*	.56*

* $p < .05$, ** $p < .01$

Results: Integrated STEM

Motivations, Costs and Achievement Goals

Table 55 shows descriptive statistics for students in each grade band.

- Motivational factors (perceptions of own talent in integrated STEM, instrumental, attainment and intrinsic values) were slightly above the midpoint, indicating that students were positively motivated in their integrated STEM subject.
- For negative costs, mean scores varied around the midpoint, indicating that integrated STEM was experienced as moderately difficult, provoking moderate levels of effort cost, and as somewhat psychologically taxing. This was more so for older students.
- Effort exerted mean scores were above the scale midpoint, indicating moderate levels of effort investment in integrated STEM.
- Mastery goals were endorsed more than performance goals for integrated STEM.

Student-Perceived Integrated STEM Classroom and Teacher Factors

Table 56 shows descriptive statistics for students in each grade band.

- Classroom climate was largely perceived positively.
  - Mastery climates were more prevalent and endured into secondary school, whereas performance climate remained relatively low. Teacher enthusiasm was perceived positively.
  - Cognitive dimensions of academic challenge and curiosity were mostly rated above the midpoint.
- Dimensions of classroom practice (inquiry learning, teacher directed learning, teacher support, data literacy) were rated between 2 (some lessons) and 3 (many lessons).
  - Use of materials/tools and representational tools was well below the scale midpoint.
- Student-perceived beliefs that their teacher held positive expectations that they could succeed in integrated STEM were quite high; students also perceived their teacher to think they found integrated STEM moderately difficult.
  - Students perceived that their teachers believed integrated STEM to be of high value.
  - In general, students experienced positive relationships with their integrated STEM teacher.

Table 55: Motivations, Costs and Achievement Goals in Integrated STEM

Integrated STEM	**Whole Sample**	
	Lower secondary Y7-8 *M* (SD)	**Mid secondary Y9-10 *M* (SD)**
[a]***Motivations***	*n* = 53	*n* = 47
Perceived talent (α = .87)	4.06 (1.73)	4.89 (1.38)
Instrumental value (α = .92)	4.14 (1.91)	5.10 (1.40)
Attainment value (α = .93)	4.60 (1.74)	3.92 (1.89)
Intrinsic value	4.49 (1.90)	5.62 (1.26)
[a]***Costs***	*n* = 53	*n* = 47
Difficulty (α = .91)	3.60 (1.78)	4.62 (1.53)
Effort cost (α = .91)	4.19 (1.79)	5.15 (1.37)
Psychological cost (α = .88)	3.24 (1.72)	3.68 (1.77)
[a]***Effort exerted* (α = .91)**	4.17 (1.78)	5.15 (1.36)
[b]***Achievement goals***	*n* = 52	*n* = 44
Mastery (α = .91)	3.17 (1.11)	3.85 (0.94)
Perf.-approach (α = .92)	2.60 (1.15)	3.28 (1.17)
Perf.-avoidance (α = .88)	2.70 (1.02)	3.25 (1.18)

[a] 1: not at all, 7: extremely; [b] 1: not at all true, 3: somewhat true, 5: very true

Table 56: Student-Perceived Classroom and Teacher Factors in Integrated STEM

Integrated STEM	Whole Sample	
	Lower secondary Y7-8 *M* (SD)	**Mid secondary Y9-10 *M* (SD)**
Learning environment	*n* = 53	*n* = 51
[a]Mastery climate (α = .92)	4.81 (1.64)	5.19 (1.35)
[a]Performance climate (α = .80)	3.52 (1.60)	4.17 (1.55)
[a]Teacher enthusiasm (α = .96)	4.65 (1.75)	5.18 (1.47)
[b]Academic challenge (α = .83)	3.02 (1.08)	3.53 (0.90)
[b]Curiosity (α = .89)	3.12 (1.19)	3.56 (0.94)
Classroom practice	*n* = 54	*n* = 50
[c]Inquiry learning (α = .75)	2.33 (0.81)	2.49 (0.59)
[c]Teacher-directed (α = .90)	2.80 (0.72)	2.91 (0.70)
[c]Teacher support (α = .95)	2.98 (0.88)	3.15 (0.71)
[c]Data literacy (α = .91)	2.42 (0.79)	2.45 (0.67)
[d]Use of materials/tools (α = .79)	2.25 (0.62)	2.43 (0.58)
[d]Use of representational tools (α = .83)	2.25 (0.83)	2.30 (0.72)
[a]Student-perceived teacher beliefs	*n* = 54	*n* = 50
Expectation (α = .82)	4.51 (1.39)	5.06 (1.43)
Difficulty (α = .64)	3.84 (1.44)	4.43 (1.19)
Value (α = .72)	4.74 (1.54)	5.17 (1.21)
Relationship (α = .92)	4.11 (1.77)	4.95 (1.46)

[a] 1: not at all, 7: extremely
[b] 1: strongly disagree, 5: strongly agree
[c] 1: never or almost never, 2: some lessons, 3: many lessons, 4: almost every lesson or every lesson
[d] 1: not at all, 7: every lesson

Pearson correlations measured the extent of relationship between the two sets of integrated STEM factors: students' motivations, costs and achievement goals; and student-perceived classroom and teacher factors (see Table 57). Asterisked relationships were statistically significant. Correlations can range in strength from 0 (no relationship) to ±1 (perfect correspondence); positive numbers indicate a same direction of relationship and negative numbers the opposite. Stronger correlations $r \geq .50$ (that is, 25% shared variance) have been underlined for emphasis and summarised below.

- Students' motivations (perceived talent and different kinds of values) in integrated STEM, their effort exertion and own mastery goals for learning were the factors that appeared most responsive to their classroom environments and teacher factors. There were several strong relationships also with students' perceptions of integrated STEM being difficult.
- Mastery classroom goal climates were strongly positively correlated with students' integrated STEM motivations, efforts exerted and own mastery goals. Performance goal climates strongly related to students endorsing performance goals themselves.
- Teacher enthusiasm, academic challenge and promoting curiosity strongly related to students' motivations, effort exertion and own mastery goals for learning.
- Inquiry learning, teacher-directed learning and teacher support in integrated STEM showed strong associations with students' motivations, efforts and mastery goals. Inquiry learning also showed strong associations with two of the negative student factors: perceived difficulty and performance goals. Data literacy activities proved beneficial; use of materials and representational tools, less so.
- Student-perceived teacher positive expectations, value and relationship quality also strongly related to students' integrated STEM motivations, effort exertion and own mastery goals for learning.

Table 57: Correlations of Students' Motivations, Costs and Achievement Goals with Student-Perceived Classroom and Teacher Factors in Integrated STEM (Listwise N = 96)

	Motivations				Costs			Effort	Achievement goals		
	Perceived talent	Instrumental value	Attainment value	Intrinsic value	Difficulty	Effort cost	Psychological cost	Effort exerted	Mastery goals	Perf. approach goals	Perf. avoidance goals
Learning environment											
Mastery climate	.57*	.63*	.54*	.60*	.46*	.28*	.28*	.64*	.61*	.37*	.45*
Performance climate	.31*	.39*	.48*	.34*	.49*	.41*	.45*	.33*	.44*	.54*	.53*
Teacher enthusiasm	.58*	.66*	.57*	.64*	.47*	.28*	.27*	.66*	.63*	.34*	.43*
Academic challenge	.69*	.78*	.79*	.71*	.55*	.25**	.32*	.77*	.78*	.47*	.49*
Curiosity	.52*	.66*	.66*	.56*	.45*	.22**	.24**	.68*	.71*	.40*	.40*
Classroom practice											
Inquiry learning	.64*	.66*	.68*	.58*	.53*	.33*	.37*	.71*	.57*	.52*	.49*
Teacher-directed	.52*	.58*	.54*	.56*	.30*	.10	.30*	.63*	.54*	.30*	.34*
Teacher support	.58*	.66*	.63*	.60*	.51*	.20**	.25**	.64*	.57*	.40*	.46*
Data literacy	.48*	.58*	.63*	.49*	.54*	.44*	.48*	.58*	.51*	.45*	.46*
Use of material/tools	.47*	.43*	.46*	.42*	.46*	.47*	.46*	.46*	.44*	.39*	.37*
Representational tools	.31*	.39*	.44*	.38*	.47*	.37*	.47*	.45*	.34*	.27*	.32*
Student-perceived teacher beliefs											
Expectation	.72*	.69*	.65*	.62*	.36*	.22**	.21**	.70*	.73*	.43*	.46*
Difficulty	.43*	.40*	.43*	.30*	.58*	.32*	.40*	.44*	.46*	.41*	.43*
Value	.67*	.68*	.66*	.58*	.45*	.23**	.27*	.66*	.63*	.46*	.50*
Relationship	.57*	.65*	.64*	.54*	.50*	.34*	.32*	.60*	.57*	.51*	.53*

* $p < .05$, ** $p < .01$

Results: Design & technology (secondary school)

Motivations, Costs and Achievement Goals

Table 58 shows descriptive statistics for students in each grade band.

- Motivational factors (perceptions of own talent, instrumental, attainment and intrinsic values in design & technology) were mostly substantially above the midpoint, indicating that students were positively motivated in design & technology.
- For negative costs, effort cost was elevated, perceived difficulty was moderate, and psychological cost lower.
- Effort exerted in design & technology indicated quite high levels of effort being invested.
- Mastery goals were more likely to be higher endorsed than performance goals for students in design & technology.

Table 58: Student Motivations, Costs and Achievement Goals in Design & Technology

Design & Technology	**Whole Sample**	
	Lower secondary Y7-8 *M* (SD)	**Mid secondary Y9-10 *M* (SD)**
[a]***Motivations***	*n* = 23	*n* = 2
Perceived talent (α = .89)	4.65 (1.31)	5.25 (0.35)
Instrumental value (α = .76)	4.66 (1.14)	5.33 (0.00)
Attainment value (α = .85)	4.33 (1.50)	5.33 (0.47)
Intrinsic value	5.09 (1.47)	5.00 (0.00)
[a]***Costs***	*n* = 23	*n* = 2
Difficulty (α = .84)	3.48 (1.56)	6.00 (0.00)
Effort cost (α = .83)	5.28 (1.10)	4.75 (0.35)
Psychological cost (α = .96)	2.67 (1.67)	2.67 (1.67)
[a]***Effort exerted* (α = .83)**	5.28 (1.09)	4.75 (0.35)
[b]***Achievement goals***	*n* = 23	*n* = 2
Mastery (α = .86)	3.88 (0.86)	4.00 (0.00)
Perf.-approach (α = .90)	3.90 (0.84)	2.75 (1.16)
Perf.-avoidance (α = .83)	3.08 (0.96)	4.00 (0.00)

[a] 1: not at all, 7: extremely
[b] 1: not at all true, 3: somewhat true, 5: very true

Student-Perceived Design & Technology Classroom and Teacher Factors

Table 59 shows descriptive statistics for students in each grade band.

- Mastery classroom climates were strongly endorsed in design & technology. Unfortunately, performance climates were also strongly endorsed among secondary school students. Students rated their teacher's enthusiasm highly.
  - Cognitive dimensions of academic challenge and curiosity were rated above the scale midpoint for design & technology classes.
- Dimensions of classroom practice (inquiry learning, teacher-directed learning, teacher support, data literacy) were rated between 2 (some lessons) and 3 (many lessons). Use of materials/tools and representational tools was low.
- Students perceived their design & technology teacher to hold positive expectations that they could succeed, while also believing they found design & technology moderately difficult.
  - Students perceived their teachers to moderately value design & technology.
  - Students rated their relationship quality with their design & technology teacher as moderately positive.

Table 59: Student-perceived Classroom and Teacher Factors in Design & Technology

Design & Technology	Whole Sample	
	Lower secondary Y7-8 *M* (SD)	**Mid secondary Y9-10 *M* (SD)**
Learning environment	*n* = 26	*n* = 2
[a]Mastery climate (α = .89)	5.28 (1.52)	5.67 (0.47)
[a]Performance climate (α = .80)	3.79 (1.68)	5.67 (0.47)
[a]Teacher enthusiasm (α = .89)	5.27 (1.44)	5.33 (0.94)
[b]Academic challenge (α = .84)	3.63 (0.77)	3.75 (0.35)
[b]Curiosity (α = .95)	3.56 (0.97)	3.25 (0.35)
Classroom practice	*n* = 25	*n* = 2
[c]Inquiry learning (α = .76)	2.40 (0.58)	2.75 (0.00)
[c]Teacher-directed (α = .89)	2.90 (0.72)	2.88 (0.18)
[c]Teacher support (α = .89)	3.11 (0.69)	3.00 (0.00)
[c]Data literacy (α = .94)	2.18 (0.84)	3.00 (0.00)
[d]Use of materials/tools (α = .78)	2.48 (0.77)	2.25 (1.06)
[d]Use of representational tools (α = .83)	1.95 (0.82)	2.33 (0.47)
[a]Student-perceived teacher beliefs	*n* = 25	*n* = 2
Expectation (α = .84)	5.08 (1.00)	5.25 (0.35)
Difficulty (α = .36)	4.42 (1.19)	3.50 (0.71)
Value (α = .68)	5.04 (1.10)	4.25 (1.06)
Relationship (α = .86)	4.76 (1.67)	4.25 (0.35)

[a] 1: not at all, 7: extremely; [b] 1: strongly disagree, 5: strongly agree; [c] 1: never or almost never, 2: some lessons, 3: many lessons, 4: almost every lesson or every lesson; [d] 1: not at all, 7: every lesson.

To examine the extent of relationship between the two sets of design & technology factors, Pearson correlations were computed between students' motivations, costs and achievement goals; and student-perceived classroom and teacher factors in design & technology (see Table 60). Asterisked relationships were statistically significant. Correlations can range in strength from 0 (no relationship) to ±1 (perfect correspondence); positive numbers indicate a same direction of relationship and negative numbers the opposite. Stronger correlations r ≥ .50 (that is, 25% shared variance) have been underlined for emphasis and summarised below.

- In design & technology, students' motivations and costs appeared most responsive to their classroom environment and teacher factors.
- Most influential learning environment factors in design & technology appeared to be academic challenge and promoting curiosity. Classes characterised by academic challenge positively related to students perceiving themselves as talented at design & technology, but also promoted students' own performance goals. Classes that promoted curiosity related strongly to students' perceived talent, as well as their effort exertion.
  - Mastery climate showed no significant associations in design & technology; performance climate had only one significant correlation with students' elevated psychological cost. Teacher enthusiasm related only to students' effort exertion and own mastery goals.
- Classroom practices showed few relationships with student factors. None for inquiry learning. Teacher-directed learning and teacher support mainly showed a protective relationship with lower negative costs among students studying design & technology.
  - There were no relationships with data literacy activities or use of materials/tools. The only correlations with representational tools were that more use of representational tools related to students experiencing greater psychological cost and adopting performance-approach goals.
- Student-perceived teacher beliefs showed various positive relationships with design & technology students' motivations and effort exertion – most especially with students' belief that their design & technology teacher held positive expectations for their success.

Table 60: Correlations of Students' Motivations, Costs and Achievement Goals with Student-Perceived Classroom and Teacher Factors in Design & Technology (Listwise N = 26)

	Motivations				Costs			Effort	Achievement goals		
	Perceived talent	Instrumental value	Attainment value	Intrinsic value	Difficulty	Effort cost	Psychological cost	Effort exerted	Mastery goals	Perf. approach goals	Perf. avoidance goals
Learning environment											
Mastery climate	.20	.03	.03	-.17	-.18	-.24	-.33	.34	.24	.13	.23
Performance climate	.06	.26	.18	.22	.32	.37	.42**	-.02	-.03	.22	.08
Teacher enthusiasm	.29	.18	.13	-.04	-.15	-.17	-.26	.46**	.40**	.14	.30
Academic challenge	.49*	.33	.30	.19	-.04	-.10	-.09	.46**	.47**	.55*	.57*
Curiosity	.62*	.36	.34	.34	-.05	-.08	-.16	.68*	.28	.35	.37
Classroom practice											
Inquiry learning	.25	.21	.35	.07	-.06	-.35	-.17	-.01	.24	.16	.31
Teacher-directed	.04	-.05	-.11	-.27	-.51*	-.43**	-.58*	.15	.35	-.07	.08
Teacher support	-.11	-.10	-.10	-.28	-.47**	-.66*	-.54*	-.11	.29	-.04	.02
Data literacy	.11	.30	.37	.22	.15	-.18	.02	-.18	.22	.34	.26
Use of material/tools	-.02	.20	.24	.22	.09	-.01	.22	-.28	-.21	.32	.00
Representational tools	.10	.26	.29	.35	.37	.38	.58*	-.22	.11	.55*	.22
Student-perceived teacher beliefs											
Expectation	.83*	.57*	.56*	.36	.05	.13	.04	.74*	.32	.32	.41**
Difficulty	.36	.56*	.48**	.52*	.42**	.39**	.45**	.27	.06	.20	.20
Value	.55*	.49**	.36	.42**	.10	.13	.00	.58*	.25	.36	.24
Relationship	.45**	.31	.26	.10	.15	.19	.10	.72*	.43**	.40**	.50*

* $p < .05$, ** $p < .05$

Results: Digital technologies (secondary school)

Motivations, Costs and Achievement Goals

Table 61 shows descriptive statistics for students in each grade band.

- Motivational factors (perceptions of own talent, instrumental, attainment and intrinsic values in digital technologies) were all rated on average at or above the midpoint, indicating students to be positively motivated in digital technologies.
- For negative costs, mean scores were also rated around the midpoint, indicating that digital technology was experienced as moderately difficult, provoking moderate levels of effort cost and being psychologically taxing.
- Students reported quite high effort exertion in digital technologies.
- Mastery goals were most endorsed, closely followed by harmful performance-avoidance goals, and then performance-approach goals for digital technology students.

Table 61: Students' Motivations, Costs and Achievement Goals in Digital Technologies

Digital Technologies	**Whole Sample**	
	Lower secondary Y7-8 *M* (SD)	**Mid secondary Y9-10 *M* (SD)**
[a]*Motivations*	*n* = 23	*n* = 9
Perceived talent (α = .95)	4.09 (1.88)	5.28 (1.12)
Instrumental value (α = .96)	4.22 (1.76)	5.44 (0.97)
Attainment value (α = .97)	4.07 (1.91)	5.19 (1.16)
Intrinsic value	4.35 (1.85)	5.67 (1.00)
[a]*Costs*	*n* = 22	*n* = 9
Difficulty (α = .84)	4.16 (1.62)	5.50 (1.03)
Effort cost (α = .85)	3.84 (2.01)	3.67 (1.58)
Psychological cost (α = .92)	3.91 (1.93)	4.89 (1.45)
[a]*Effort exerted* (α = .92)	4.28 (1.69)	5.50 (1.03)
[b]*Achievement goals*	*n* = 22	*n* = 9
Mastery (α = .91)	3.53 (1.01)	3.85 (0.56)
Perf.-approach (α = .92)	2.98 (1.15)	3.26 (1.10)
Perf.-avoidance (α = .88)	3.05 (1.21)	3.59 (0.93)

[a] 1: not at all, 7: extremely
[b] 1: not at all true, 3: somewhat true, 5: very true

Student-Perceived Digital Technologies Classroom and Teacher Factors

Table 62 shows descriptive statistics for students in each grade band.

- Classroom climates in digital technologies were largely positive.
  - A mastery climate was mostly rated higher than a performance climate, and students positively rated their teacher's enthusiasm.
  - Cognitive dimensions of academic challenge and curiosity were above the scale midpoint.
- Dimensions of classroom practice (inquiry learning, teacher-directed learning, teacher support, data literacy) were rated between 2 (some lessons) and 3 (many lessons).
  - Use of materials/tools and representational tools was low.
- Student-perceived teacher beliefs were above the midpoint indicating positive expectations that they could succeed in digital technologies while also perceiving digital technologies to be moderately difficult.
  - Students perceived that their teacher highly valued digital technologies.
  - In general, students experienced quite positive relationships with their digital technologies teacher.

Table 62: Student-Perceived Classroom and Teacher Factors in Digital Technologies

Digital Technologies	Whole Sample	
	Lower secondary Y7-8 *M* (SD)	**Mid secondary Y9-10 *M* (SD)**
Learning environment	*n* = 25	*n* = 9
[a]Mastery climate (α = .95)	4.53 (1.77)	5.07 (1.28)
[a]Performance climate (α = .90)	3.84 (1.73)	4.74 (1.47)
[a]Teacher enthusiasm (α = .89)	4.45 (1.79)	5.26 (0.97)
[b]Academic challenge (α = .84)	3.26 (1.05)	3.83 (0.87)
[b]Curiosity (α = .95)	3.24 (1.15)	3.78 (0.97)
Classroom practice	*n* = 23	*n* = 9
Inquiry learning (α = .75)	2.43 (0.78)	3.00 (0.66)
[c]Teacher-directed (α = .90)	2.64 (0.83)	2.78 (0.91)
[c]Teacher support (α = .95)	2.78 (0.90)	2.44 (0.64)
[c]Data literacy (α = .86)	2.41 (0.93)	2.81 (0.82)
[d]Use of materials/tools (α = .36)	2.65 (0.87)	2.67 (0.71)
[d]Use of representational tools (α = .94)	2.17 (1.01)	2.63 (1.03)
[a]Student-perceived teacher beliefs	*n* = 26	*n* = 9
Teacher expectation (α = .82)	4.69 (1.44)	5.44 (0.95)
Teacher difficulty (α = .70)	4.35 (1.34)	4.94 (1.10)
Teacher value (α = .92)	4.69 (1.59)	5.28 (0.97)
Teacher relationship (α = .96)	4.37 (1.59)	4.94 (1.10)

[a] 1: not at all, 7: extremely; [b] 1: strongly disagree, 5: strongly agree; [c] 1: never or almost never, 2: some lessons, 3: many lessons, 4: almost every lesson or every lesson; [d] 1: not at all, 7: every lesson.

To examine the extent of relationship between the two sets of digital technologies factors, Pearson correlations were computed between students' motivations, costs and achievement goals; and student-perceived classroom and teacher factors in design & technology (see Table 63). Asterisked relationships were statistically significant. Correlations can range in strength from 0 (no relationship) to ±1 (perfect correspondence); positive numbers indicate a same direction of relationship and negative numbers the opposite. Stronger correlations r ≥ .50 (that is, 25% shared variance) have been underlined for emphasis and summarised below.

- In digital technologies, students' motivations (perceived talent and different kinds of values), their effort exerted and own goals for learning were factors that appeared most responsive to their classroom environments and teacher factors. There were also several strong relationships with students' negative cost perceptions of digital technologies being difficult and provoking effort cost.
- Mastery classroom goal climates were strongly positively correlated with students' digital technologies motivations, efforts exerted, and own mastery goals. Performance goal climates showed weaker relationships with those factors; and, strongly related to students' negative costs and endorsing performance goals.
  - Teacher enthusiasm, academic challenge and promoting curiosity strongly related to students' digital technologies motivations, effort exertion and own mastery goals for learning.
- Inquiry learning, teacher-directed learning, data literacy, and use of materials and representational tools in digital technologies showed strong associations with students' motivations, efforts, and mastery goals for learning.
  - They also displayed strong associations with negative cost factors and performance goals.
  - Teacher support showed few and weaker associations among digital technologies students.
- Student-perceived teacher beliefs strongly related to students' motivations, effort exerted, and mastery goals for learning. Student-perceived teacher beliefs that they found digital technologies difficult, or believing that their teacher highly valued digital technologies; additionally, related strongly to students' negative costs (difficulty and effort cost) and performance goals in digital technologies.

Table 63: Correlations of Students' Motivations, Costs and Achievement Goals with Student-Perceived Classroom and Teacher Factors in Digital Technologies (Listwise N = 30)

	Motivations				Costs			Effort	Achievement goals		
	Perceived talent	Instrumental value	Attainment value	Intrinsic value	Difficulty	Effort cost	Psychological cost	Effort exerted	Mastery goals	Perf. approach goals	Perf. avoidance goals
Learning environment											
Mastery climate	.79*	.76*	.61*	.68*	.35	.41**	.15	.63*	.69*	.35	.43**
Performance climate	.61*	.51*	.61*	.48*	.59*	.66*	.42**	.40**	.41**	.80*	.70*
Teacher enthusiasm	.79*	.80*	.64*	.70*	.40**	.44**	.16	.68*	.67*	.37**	.46**
Academic challenge	.78*	.71*	.65*	.60*	.44**	.47*	.23	.63*	.68*	.41**	.38**
Curiosity	.74*	.67*	.62*	.57*	.47*	.51*	.28	.61*	.61*	.52*	.53*
Classroom practice											
Inquiry learning	.78*	.74*	.75*	.64*	.60*	.57*	.31	.62*	.66*	.60*	.56*
Teacher-directed	.61*	.68*	.60*	.59*	.53*	.43**	.28	.57*	.67*	.44**	.42**
Teacher support	.44**	.41**	.23	.35	.02	.09	.08	.27	.44**	-.01	.04
Data literacy	.71*	.63*	.71*	.51*	.59*	.62*	.39**	.44**	.60*	.62*	.44**
Use of material/tools	.60*	.66*	.63*	.67*	.51*	.25	.34	.57*	.66*	.42**	.47*
Representational tools	.69*	.60*	.70*	.48*	.54*	.54*	.32	.48*	.52*	.69*	.51*
Student-perceived teacher beliefs											
Expectation	.71*	.75*	.77*	.70*	.48*	.32	.29	.73*	.73*	.52*	.54*
Difficulty	.65*	.72*	.72*	.69*	.76*	.62*	.44**	.67*	.72*	.60*	.57*
Value	.77*	.84*	.71*	.80*	.51*	.39**	.25	.77*	.83*	.25	.41**
Relationship	.79*	.72*	.55*	.64*	.39**	.49*	.19	.58*	.70*	.36	.44**

* $p < .05$, ** $p < .01$

Results: Technology (Primary school)

Student Motivations, Perceived Classroom and Teacher Factors

Table 64 shows descriptive statistics for students in each grade band.

- Mastery goals were mostly more strongly endorsed than performance approach goals in technology at primary school.
- Maladaptive performance-avoidance goals were concerningly rated above the scale midpoint across all age groups.
- Learning environments were characterised more by mastery climates than performance climates, and teachers were rated as highly enthusiastic.
- Use of materials/tools and representational tools was low in technology at primary school.
- Student-perceived teacher beliefs were rated above the scale midpoint for students' thinking their teacher believed they could succeed in technology, and that they found it not very difficult. Students thought their teacher valued technology moderately, and experienced moderate relationship quality with their primary school technology teacher.

Table 64: Student Motivations, and Perceived Classroom and Teacher Factors in Technology (Primary)

Technology (Primary)	**Whole sample**
	Primary Y4-6 *M* (SD)
[a]***Achievement goals***	*n* = 108
Mastery (α = .85)	3.66 (0.99)
Perf.-approach (α = .79)	2.88 (1.20)
Perf.-avoidance (α = .78)	3.04 (1.10)
[b]***Learning environment***	*n* = 184
Mastery climate (α = .84)	5.68 (1.30)
Performance climate (α = .76)	3.79 (1.71)
Teacher enthusiasm (α = .71)	5.43 (1.35)
[c]***Classroom practice***	*n* = 118
Use of materials/tools (α = .23)	2.13 (0.57)
Use of representational tools (α = .71)	2.26 (0.65)
[d]***Student-perceived teacher beliefs***	*n* = 112
Expectation (α = .82)	4.44 (1.45)
Difficulty (α = .42)	3.78 (1.24)
Value (α = .60)	4.45 (1.34)
Relationship (α = .71)	4.13 (1.49)

[a] 1: not at all true, 3: somewhat true, 5: very true
[b] 1: not at all, 7: extremely
[c] 1: not at all, 7: every lesson
[d] 1: not at all, 7: extremely.

Correlations between students' achievement goals and student-perceived classroom and teacher factors in primary school technology are reported in Table 65. The only correlations greater than .50 were that inquiry learning and relationship quality positively related to students' own mastery goals for learning technology.

Table 65: Correlations of Students' Achievement Goals with Student-Perceived Classroom and Teacher Factors in Technology (Primary) (Listwise N = 106)

	Achievement goals		
	Mastery goals	**Perf. approach goals**	**Perf. avoidance goals**
Learning environment			
Mastery climate	.30*	.04	.06
Performance climate	.15	.32*	.26*
Teacher enthusiasm	.30*	.14	.00
Academic challenge	.08	-.01	.10
Curiosity	.22**	.10	.10
Classroom practice			
Inquiry learning	.51*	.29*	.24**
Teacher-directed	.15	.19**	.14
Teacher support	.46*	.27*	.31*
Data literacy	.46*	.28*	.29*
Use of material/tools	.30*	.05	.06
Representational tools	.15	.32*	.26*
Student-perceived teacher beliefs			
Expectation	.30*	.14	.00
Difficulty	.07	-.01	.10
Value	.22**	.10	.11
Relationship	.51*	.29*	.24**

* $p < .05$, ** $p < .01$

Results: STEM-related Career Aspirations and 21st Century Skills

Career Aspirations and 21st Century Skills

Secondary school students indicated moderate interest in each STEM-related career option, especially technology-related careers, as shown in Table 66.

Students reported moderate confidence in being equipped with the necessary skills for 21st Century work.

Table 66: Students' STEM-related Career Aspirations

	Whole Sample	
	Lower secondary Y7-8 *M* (SD) *n* = 304	**Mid secondary Y9-10 *M* (SD) *n* = 185**
[a] ***STEM career aspirations***		
mathematics	3.74 (1.83)	3.65 (1.81)
science	3.67 (1.95)	3.77 (1.91)
technology	4.00 (1.85)	3.97 (1.90)
engineering	3.66 (1.85)	3.63 (1.95)
[b] ***21st Century skills* (α = .98)**	*4.17 (1.57)*	*4.22 (1.70)*

[a]1: not at all, 7: extremely;
[b]1: not at all confident, 7: completely confident

Appendix B: Research Instruments

Appendix B contains the suite of generic instruments used in the PASL research.

Teacher and student surveys are unable to be provided due to the extent of branching within the instruments unable to be reproduced adequately in print.

Semi-structured interview schedules were varied to accommodate jurisdictional advice.

The examples provided in this Appendix are broadly representative of the nature of the instrument content.

B.1 PL School: Principal Interview

B.2 PL School: Principal – Follow up Interview

B.3 PL School: Teacher Interview

B.4 PL School: Teacher – Follow up Interview

B.5 PL School: Principal Interview – Evaluation

B.6 Case Study: Principal Interview Questions

B.7 Case Study: Teacher Interview Questions

B.8 Case Study: Lesson Observation

B.9 Case Study: Focus Group Questions

B.10 WA System Case Study: Interview Questions

Principals as STEM Leaders (PASL) Building the Evidence Base for Improved STEM Learning

Principal Interview – PL school

***Please note:*

The interviewer will adapt to different school circumstances by conducting a semi-structured interview based on the following protocol.

STEM refers both to individual Science, Technology and Mathematics subject teaching as well as integrated models of STEM. Items referring to Engineering as a stand-alone discipline will not be included but treated as part of integrated STEM.

RESEARCHER COPY

School..... School #.....

Date..... Time .....

Principal..... Interviewer.....

BACKGROUND

Personal background, length of time at school, length of time as a principal, other locations etc.
How many minutes of STEM subjects are taught in each grade each week?

THE SCHOOL

1. Can you describe some of the key issues facing your school in STEM?
2. What reforms have you implemented in an attempt to address these issues?
3. How satisfied are you with these reforms?
4. What would you like to be the key focus of your work in this school in the next few years, particularly as it pertains to STEM education?

CLASSROOM PRACTICE

PEDAGOGY

We are trying to get a snap shot of STEM teaching in Australian schools and to identify any changes that have been taking place over the last 5 years or so.

5. Can you comment on what you believe to be important in terms of STEM pedagogy at your school? Does the school have a pedagogical framework? How is quality pedagogy understood and monitored at the school?

ASSESSMENT

We are interested in current STEM assessment practices in schools.

6. How is mathematics/science/technology assessment approached at the school?
7. Are there any issues or problems relating to assessment that you believe need to be addressed? (E.g. what forms of assessment as seen as more legitimate than others, what issues of in/equity arise in the types of assessment used, what issues of in/consistency arise within and beyond the school, are there any issues of misalignment between assessment, pedagogy and curriculum)?
8. How are these issues being addressed? (e.g. use of multiple assessment modes, monitoring of assessment, strategies to ensure comparability of standards)
9. What processes are in place to ensure comparability of teacher judgments/moderation?

CURRICULUM

10. Do teachers have a good sense of what it is that they are expected to teach in each of the STEM disciplines separately and integrated STEM?

11. Do you think that the curriculum has become less or more conducive to STEM teaching (both single disciplines and integrated STEM) in the last few years? Why?

12. Do you think that transient students have more seamless movements between schools in terms of curriculum continuity than they have had in the past?

EQUITY

We are interested in how schools are able to help students who are not doing as well as they should be, particularly in relation to studying STEM subjects.

13. Without identifying specific individuals, what is the situation regarding any such student groups in your school?

    Prompts:

    In what ways do specific practices and structures within the school (e.g. school climate, pedagogy, curriculum, relationships etc.) support or constrain issues of social/academic equity within the school?

14. Without identifying specific individuals, are there some groups of parents who aren't as involved in their students' education as you would like them to be?

    Has this been addressed as a problem?

SCHOOL ENVIRONMENT

15. Are there aspects of the school's environment which enhance or limit the success of STEM teaching?

16. Tell me about the leadership and decision making processes and structures in the school. What are the implications of such processes in terms of the school climate? (e.g. teacher classroom practice and their relationships with others, parents/students)

17. Tell me about your thoughts on teacher professional development for STEM disciplines and/or integrated STEM.

    Prompts: How do teachers generally view PD and what are the implications?

    What opportunities are offered? How are they managed/organised/prioritised/disseminated?

    What has been the impact of such opportunities in terms of the spread of improved practices? (E.g. Nature and extent of professional dialogue in the school

18. To what extent do you position the school and its teachers as being accountable for the success of different groups of students in the school?

    Prompts: What cultural and organisational features in the school support a sense of collective responsibility for student performance (tests, grades, attendance, discipline)?

    What is your view on the effectiveness of this?

REPORTING

19. How well do you think reporting procedures are working in your school?

    Prompts: Do you think students understand what they are achieving in relation to what is expected of them (from report cards, other forms of reporting)?

    Do you think parents/guardians understand what is expected of their children, how their child is going, how they can help their child with their learning in STEM subjects?

SYSTEMIC SUPPORTS

20. What key reforms at the system level have positively and/or negatively impacted on the teaching of STEM subjects and/or integrated STEM in the school? What supports have you had from your system for reforms that you have sought to undertake at the school?

    Prompts:

    Curriculum reform? School restructuring? New pedagogies? Can you please detail or give an example of this impact?

21. Do you think the current curriculum provides a suitable framework for preparing students for their futures?

SCENARIO (USE AS APPROPRIATE)

PRIMARY SCHOOL

You pass a classroom where the children are sitting in groups and working almost in silence from their mathematics, science or technology work books. There are worked examples of problems on the whiteboard. The teacher is sitting at the desk in the corner.

What discussion would you have with this teacher?

SECONDARY SCHOOL

You pass a mathematics, science or technology classroom where the children are folding and cutting paper or building models [this question will ask each subject area separately; as well as for integrated STEM if applicable]. They are making quite a bit of noise talking to each other. Some are working at the interactive whiteboard. Others appear to be using their tablets. The teacher is walking around the class talking to the students.

What discussion would you have with this teacher?

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Principal Interview PL Follow-up

***Please note:*

The interviewer will adapt to different school circumstances by conducting a semi-structured interview based on the following protocol.

STEM refers both to individual Science, Technology and Mathematics subject teaching as well as integrated models of STEM. Items referring to Engineering as a stand-alone discipline will not be included but treated as part of integrated STEM.

RESEARCHER COPY

School..... School #.....

Date..... Time .....

Principal..... Interviewer.....

INTRODUCTION

Anything pertinent during PASL and/or subsequent to completing PASL (only if necessary to warm up the interviewee).

CLASSROOM PRACTICE

PEDAGOGY

We are trying to identify any changes that have been taking place since we last spoke.

1. Can you comment on how you and/or your teachers (without identifying specific individuals) go about curriculum planning?
    i. Prompts: Do you/they plan with others across the same year level? Do you/they use the Australian curriculum in your planning?
2. Can you comment on the way you teach your classes, and whether your teaching has changed in any way in recent times?
    i. Prompts: - what are you hoping to achieve in your lessons?
    ii. How would you describe your best teaching?
    iii. Do you have special strategies for students who are underachieving? (Looking for comments relating to intellectual quality and connectedness)
3. Without identifying specific individuals. Can you comment on the way your teachers teach their classes, and whether you perceive that their teaching has changed in any way in recent times?
    i. Prompts: - in what they're hoping to achieve in your lessons?
    ii. Their best teaching?
    iii. The special strategies they use for students who are underachieving? (Looking for comments relating to intellectual quality and connectedness)

CURRICULUM

4. What do you understand it is that your teachers are expected to teach in mathematics/science/technology?
5. Do you think that the curriculum has become less or more conducive to STEM teaching (both single disciplines and integrated STEM) in the last few years? Why?
6. Do you think that transient students have more seamless movements between schools in terms of curriculum continuity than they have had in the past?

ASSESSMENT

We are interested in current assessment practices in schools.

7. What kinds of student work does your school rely on most to assess learning?
   a. Why do you think this work is useful for assessment?
   b. When your teachers grade the work, what aspects of the work do you think are most important to them/would you like them to view as most important?
   c. Is there other information you would like your teachers to use but for some reason they don't? Why?
   d. How do your teachers go about assessing integrated STEM learning?

8. In your experience, how consistent are the standards applied in allocating grades to student work:
   a. Across classes in this school?
   b. Across schools?
   c. Strategies to ensure comparability of standards?

EQUITY

We are interested in how schools are able to help students who are not doing as well as they should be, particularly in relation to studying STEM subjects.

9. Without identifying specific individuals, what is the situation regarding any such student groups in your school?
   a. Prompts: Who are they?
      i. What have you done in the school to deal with this issue?

10. Without identifying specific individuals, are there some groups of parents who aren't as involved in their students' education as you would like them to be?
    ii. Has this been addressed as a problem?

SCHOOL ENVIRONMENT

11. Are there aspects of the school's environment which enhance or limit the success of STEM teaching?

12. Tell me about the leadership and decision-making processes and structures in the school. What are the implications of such processes in terms of the school climate? (e.g. teacher classroom practice and their relationships with others, parents/students)

13. Tell me about your thoughts on teacher professional development for STEM disciplines and/or integrated STEM.

    Prompts: How do teachers generally view PD and what are the implications?

    What opportunities are offered? How are they managed/organised/prioritised/disseminated?

    What has been the impact of such opportunities in terms of the spread of improved practices? (E.g. Nature and extent of professional dialogue in the school

14. To what extent do you position the school and its teachers as being accountable for the success of different groups of students in the school?

    Prompts: What cultural and organisational features in the school support a sense of collective

responsibility for student performance (tests, grades, attendance, discipline)?

What is your view on the effectiveness of this?

REPORTING

15. How well do you think reporting procedures are working in your school?

    Prompts: Do you think students understand what they are achieving in relation to what is expected of them (from report cards, other forms of reporting)?

    Do you think parents/guardians understand what is expected of their children, how their child is going, how they can help their child with their learning in STEM subjects?

SYSTEMIC SUPPORTS

16. What key reforms at the system level have positively and/or negatively impacted on the teaching of STEM subjects and/or integrated STEM in the school? What supports have you had from your system for reforms that you have sought to undertake at the school?

    Prompts:

    Curriculum reform? School restructuring? New pedagogies? Can you please detail or give an example of this impact?

17. Do you think the current curriculum provides a suitable framework for preparing students for their futures?

LEADERSHIP

We are interested in the role the school leaders (principal, discipline leaders) play in resourcing and supporting STEM teaching and learning, and in their importance to establishing a STEM culture throughout the school.

18. What is your experience of leading your school since you completed the PASL PL?

    Prompts:

    a. What kinds of things have you initiated and/or maintained or enhanced in support of STEM?
    b. What policies, procedures and/or guidelines have you developed and/or implement in support STEM teaching and learning?
    c. What evidence do you have that they are helpful?
    d. Without identifying specific individuals, what other leadership roles have you initiated and/or maintained or enhanced in support of STEM?
    e. What evidence do you have that these people are helpful in contributing to a positive STEM environment?
    f. What evidence can you point to of a STEM culture in your school?
    g. Other comments?

Principals as STEM Leaders (PASL) Building the Evidence Base for Improved STEM Learning

Teacher Interview – PL school

***Please note:*

The interviewer will adapt to different school circumstances by conducting a semi-structured interview based on the following protocol.

STEM refers both to individual Science, Technology and Mathematics subject teaching as well as integrated models of STEM. Items referring to Engineering as a stand-alone discipline will not be included but treated as part of integrated STEM.

RESEARCHER COPY

School..... School #.....

Date..... Time .....

Principal..... Interviewer.....

INTRODUCTION

Background, personal history re school, teaching, other occupations etc. (only if necessary to warm up the interviewee). If time is short important to get to the QCAR questions in bold.

CLASSROOM PRACTICE

PEDAGOGY

We are trying to get a snap shot of STEM teaching in Australian schools and to identify any changes that have been taking place over the last 5 years or so.

1. Can you comment on how you go about your curriculum planning?
    i. Prompts: Do you plan with others across the same year level? How do you use the Australian curriculum or state-based curriculum documents in your planning?
2. Can you comment on the lesson we are about to see/have just seen in terms of how typical it is, and whether your teaching has changed in any way in recent times?
    i. Prompts: - what were you hoping to achieve in this lesson?
    ii. How would you describe your best teaching?
    iii. Do you have special strategies for students who are underachieving? (Looking for comments relating to intellectual quality and connectedness)

CURRICULUM

3. Do you have a good sense of what it is that you are expected to teach in mathematics/ science/technology?
4. Do you think that the curriculum has become less or more conducive to STEM teaching (both single disciplines and integrated STEM) in the last few years? Why?
5. Do you think that transient students have more seamless movements between schools in terms of curriculum continuity than they have had in the past?

ASSESSMENT

We are interested in current assessment practices in schools.

6. What kinds of student work do you rely on most to assess learning?
    a. Why do you think this work is useful for assessment?
    b. When you grade the work, what aspects of the work are most important to you?
    c. Is there other information you would like to use but for some reason don't? Why?
    d. How do you assess integrated STEM learning?

7. In your experience, how consistent are the standards applied in allocating grades to student work:
    a. Across classes in this school?
    b. Across schools?
    c. Strategies to ensure comparability of standards?

EQUITY

We are interested in how schools are able to help students who are not doing as well as they should be, particularly in relation to studying STEM subjects.

8. Without identifiying specific individuals, what is the situation regarding any such student groups in your school?
   a. Prompts: ?
      i. What has been done in your class or in the school to deal with this issue?

SCENARIO (USE AS APPROPRIATE)

These questions are hypothetical and do not, in any way, represent any specific individual or group.

PRIMARY SCHOOL

You pass a classroom where the children are sitting in groups and working almost in silence from their mathematics/science or technology work books. There are worked examples of problems on the whiteboard. The teacher is sitting at the desk in the corner.

What discussion would you have with this teacher?

SECONDARY SCHOOL

You pass a mathematics, science or technology classroom where the children are folding and cutting paper or building models [this question will ask each subject area separately; as well as for integrated STEM if applicable]. They are making quite a bit of noise talking to each other. Some are working at the interactive whiteboard. Others appear to be using their tablets. The teacher is walking around the class talking to the students.

What discussion would you have with this teacher?

Principals as STEM Leaders (PASL)
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Teacher Interview – PL school

***Please note:*

The interviewer will adapt to different school circumstances by conducting a semi-structured interview based on the following protocol.

STEM refers both to individual Science, Technology and Mathematics subject teaching as well as integrated models of STEM. Items referring to Engineering as a stand-alone discipline will not be included but treated as part of integrated STEM.

RESEARCHER COPY

School..... School # .....

Date..... Time .....

Principal..... Interviewer .....

INTRODUCTION

Anything pertinent during PASL and/or subsequent to completing PASL (only if necessary to warm up the interviewee).

CLASSROOM PRACTICE

PEDAGOGY

We are trying to identify any changes that have been taking place since we last spoke (i.e. prior to your principal participation in the PASL programme)

19. Can you comment on how you go about your curriculum planning?
    i. Prompts: Do you plan with others across the same year level? How do you use the Australian curriculum or state-based curriculum documents in your planning?

20. Can you comment on the lesson we are about to see/have just seen in terms of how typical it is, and whether your teaching has changed in any way in recent times?
    i. Prompts: - what were you hoping to achieve in this lesson?
    ii. How would you describe your best teaching?
    iii. Do you have special strategies for students who are underachieving? (Looking for comments relating to intellectual quality and connectedness)

CURRICULUM

21. Do you have a good sense of what it is that you are expected to teach in mathematics/science/technology?
22. Do you think that the curriculum has become less or more conducive to STEM teaching (both single disciplines and integrated STEM) in the last few years? Why?
23. Do you think that transient students have more seamless movements between schools in terms of curriculum continuity than they have had in the past?

ASSESSMENT

We are interested in current assessment practices in schools.

24. What kinds of student work do you rely on most to assess learning?
    a. Why do you think this work is useful for assessment?
    b. When you grade the work, what aspects of the work are most important to you?
    c. Is there other information you would like to use but for some reason don't? Why?
    d. How do you assess integrated STEM learning?

25. In your experience, how consistent are the standards applied in allocating grades to student work:
    a. Across classes in this school?
    b. Across schools?
    c. Strategies to ensure comparability of standards?

EQUITY

We are interested in how schools are able to help students who are not doing as well as they should be, particularly in relation to studying STEM subjects.

26. Without identifiying specific individuals, what is the situation regarding any such student groups in your school?
    a. Prompts: ?
        i. What has been done in your class or in the school to deal with this issue?

LEADERSHIP

We are interested in the role the school leaders (principal, discipline leaders) play in resourcing and supporting STEM teaching and learning, and in their importance to establishing a STEM culture throughout the school.

27. What is your experience of leadership in your school since your principal completed the PASL PL?

    Prompts:

    h. What kinds of things have they initiated and/or maintained or enhanced in support of STEM?
    i. What policies, procedures and/or guidelines have they developed and/or implemented in support STEM teaching and learning?
    j. How helpful have they been in support of your STEM teaching and students' learning?
    k. Without identifying specific individuals, what other leadership roles has your principal initiated and/or maintained or enhanced in support of STEM?
    l. How is the principal and/or leadership team helping to contribute to a positive STEM environment?
    m. What evidence can you point to of a STEM culture in your school?
    n. Other comments?

Principals as STEM Leaders (PASL)
Building the Evidence Base for Improved STEM Learning

Principal Interview – Evaluation

Were you clear about the level of commitment required to participate in the project? Did the reality of what you experienced match your expectations?

What strategies did you employ to gain the commitment of your staff/ the wider school community. Did you encounter any resistance? If so, how was it overcome or resolved?

Has the disruption to your normal school routine been manageable? Are you confident that the potential benefits have outweighed any short- term inconvenience?

Has the concept of a "school cluster" been positive component of the professional learning experience? *(this may be too close to the research data?)*

Was a mentor readily available, well informed and supportive?

Was the timing of the professional learning modules convenient for you? Would you have preferred an alternative mode of delivery? What suggestions would you make to ensure the learning was accessible.

Was there any problem providing candid feedback directly to the person who delivered the professional learning? Did you feel comfortable to provide feedback that may be perceived as critical. *(proposed optional question for those team members who are delivering PL and collecting research data)*

Can you please comment upon how COVID-19 has impacted upon you as a principal, your school environment and your intentions for leading STEM in your school.

Principals as STEM Leaders (PASL) Building the Evidence Base for Improved STEM Learning

Principal Interview – Case Study

***Please note:*

The interviewer will adapt to different school circumstances by conducting a semi-structured interview based on the following protocol.

STEM refers both to individual Science, Technology and Mathematics subject teaching as well as integrated models of STEM. Items referring to Engineering as a stand-alone discipline will not be included but treated as part of integrated STEM.

RESEARCHER COPY

School..... School # .....

Date..... Time .....

Principal..... Interviewer .....

BACKGROUND

Personal background, length of time at school, length of time as a principal, other locations etc.

How many minutes of STEM subjects are taught in each grade each week?

THE SCHOOL

1. Can you describe some of the key issues facing your school in STEM?
2. What reforms have you implemented in an attempt to address these issues?
3. How satisfied are you with these reforms?
4. What would you like to be the key focus of your work in this school in the next few years, particularly as it pertains to STEM education?

CLASSROOM PRACTICE

PEDAGOGY

We are trying to get a snap shot of STEM teaching in Australian schools and to identify any changes that have been taking place over the last 5 years or so.

5. Can you comment on what you believe to be important in terms of STEM pedagogy at your school? Does the school have a pedagogical framework? How is quality pedagogy understood and monitored at the school?

ASSESSMENT

We are interested in current STEM assessment practices in schools.

6. How is mathematics/science/technology assessment approached at the school?
7. Are there any issues or problems relating to assessment that you believe need to be addressed? (E.g. what forms of assessment as seen as more legitimate than others, what issues of in/equity arise in the types of assessment used, what issues of in/consistency arise within and beyond the school, are there any issues of misalignment between assessment, pedagogy and curriculum)?
8. How are these issues being addressed? (e.g. use of multiple assessment modes, monitoring of assessment, strategies to ensure comparability of standards)
9. What processes are in place to ensure comparability of teacher judgments/moderation?

CURRICULUM

10. Do teachers have a good sense of what it is that they are expected to teach in each of the STEM disciplines separately and integrated STEM?
11. Do you think that the curriculum has become less or more conducive to STEM teaching (both single disciplines and integrated STEM) in the last few years? Why?
12. Do you think that transient students have more seamless movements between schools in terms of curriculum continuity than they have had in the past?

EQUITY

We are interested in how schools are able to help students who are not doing as well as they should be, particularly in relation to studying STEM subjects.

13. Without identifying specific individuals, what is the situation regarding any such student groups in your school?

Prompts:

In what ways do specific practices and structures within the school (e.g. school climate, pedagogy, curriculum, relationships etc.) support or constrain issues of social/academic equity within the school?

SCHOOL ENVIRONMENT

14. Are there aspects of the school's environment which enhance or limit the success of STEM teaching?

15. Tell me about the leadership and decision-making processes and structures in the school. What are the implications of such processes in terms of the school climate? (e.g. teacher classroom practice and their relationships with others, parents/students)

16. Tell me about your thoughts on teacher professional development for STEM disciplines and/or integrated STEM.

    Prompts: How do teachers generally view PD and what are the implications?

    What opportunities are offered? How are they managed/organised/prioritised/disseminated?

    What has been the impact of such opportunities in terms of the spread of improved practices? (E.g. Nature and extent of professional dialogue in the school

17. To what extent do you position the school and its teachers as being accountable for the success of different groups of students in the school?

    Prompts: What cultural and organisational features in the school support a sense of collective responsibility for student performance (tests, grades, attendance, discipline)?

    What is your view on the effectiveness of this?

REPORTING

18. How well do you think reporting procedures are working in your school?

    Prompts: Do you think students understand what they are achieving in relation to what is expected of

them (from report cards, other forms of reporting)?

Do you think parents/guardians understand what is expected of their children, how their child is going, how they can help their child with their learning in STEM subjects?

SYSTEMIC SUPPORTS

19. What key reforms at the system level have positively and/or negatively impacted on the teaching of STEM subjects and/or integrated STEM in the school? What supports have you had from your system for reforms that you have sought to undertake at the school?

    Prompts:

    Curriculum reform? School restructuring? New pedagogies? Can you please detail or give an example of this impact?

20. Do you think the current curriculum provides a suitable framework for preparing students for their futures?

SCENARIO (USE AS APPROPRIATE)

PRIMARY SCHOOL

You pass a classroom where the children are sitting in groups and working almost in silence from their mathematics, science or technology work books. There are worked examples of problems on the whiteboard. The teacher is sitting at the desk in the corner.

What discussion would you have with this teacher?

SECONDARY SCHOOL

You pass a mathematics, science or technology classroom where the children are folding and cutting paper or building models [this question will ask each subject area separately; as well as for integrated STEM if applicable]. They are making quite a bit of noise talking to each other. Some are working at the interactive whiteboard. Others appear to be using their tablets. The teacher is walking around the class talking to the students.

What discussion would you have with this teacher?

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Teacher Interview – Case Study

***Please note:*

The interviewer will adapt to different school circumstances by conducting a semi-structured interview based on the following protocol.

STEM refers both to individual Science, Technology and Mathematics subject teaching as well as integrated models of STEM. Items referring to Engineering as a stand-alone discipline will not be included but treated as part of integrated STEM.

RESEARCHER COPY

School..... School # .....

Date..... Time .....

Teacher ..... Interviewer .....

Class (subject) observed..... Grade .....

INTRODUCTION

Background, personal history re school, teaching, other occupations etc. (only if necessary to warm up the interviewee).

CLASSROOM PRACTICE

PEDAGOGY

We are trying to get a snap shot of STEM teaching in Australian schools and to identify any changes that have been taking place over the last 5 years or so.

1. Can you comment on how you go about your curriculum planning?
    i. Prompts: Do you plan with others across the same year level? Do you use the Australian curriculum in your planning?

2. <u>Two alternate questions:</u>

A. For interview with a teacher who had their classroom observed. Can you comment on the lesson we are about to see/have just seen in terms of how typical it is, and whether your teaching has changed in any way in recent times?

i. Prompts: - what were you hoping to achieve in this lesson?
ii. How would you describe your best teaching?
iii. Do you have special strategies for students who are underachieving? (Looking for comments relating to intellectual quality and connectedness)

OR

B. For interview with a teacher not involved in classroom observation. Can you comment on the way you teach your classes, and whether your teaching has changed in any way in recent times?

iv. Prompts: - what are you hoping to achieve in your lessons?
v. How would you describe your best teaching?
vi. Do you have special strategies for students who are underachieving? (Looking for comments relating to intellectual quality and connectedness)

CURRICULUM

3. Do you have a good sense of what it is that you are expected to teach in mathematics/ science/technology?
4. Do you think that the curriculum has become less or more conducive to STEM teaching (both single disciplines and integrated STEM) in the last few years? Why?
5. Do you think that transient students have more seamless movements between schools in terms of curriculum continuity than they have had in the past?

ASSESSMENT

We are interested in current assessment practices in schools.

6. What kinds of student work do you rely on most to assess learning?
    a. Why do you think this work is useful for assessment?
    b. When you grade the work, what aspects of the work are most important to you?
    c. Is there other information you would like to use but for some reason don't? Why?
    d. How do you assess integrated STEM learning?

7. In your experience, how consistent are the standards applied in allocating grades to student work:
    a. Across classes in this school?
    b. Across schools?
    c. Strategies to ensure comparability of standards?

EQUITY

We are interested in how schools are able to help students who are not doing as well as they should be, particularly in relation to studying STEM subjects.

8. Without identifying specific individuals, what is the situation regarding any such student groups in your school?
    a. Prompts: Who are they?
        i. What has been done in your class or in the school to deal with this issue?

LEADERSHIP

We are interested in the role the school leaders (principal, discipline leaders) play in resourcing and supporting STEM teaching and learning, and in their importance to establishing a STEM culture throughout the school.

9. What is your experience of leaders supporting STEM teaching and learning your school?

    a. Prompts: What roles do they undertake?
        i. Without identifying specific individuals, what kinds of things do your school leaders do in support of STEM?
        ii. What policies, procedures and/or guidelines support STEM teaching and learning?
        iii. How are they helpful?

SCENARIO (USE AS APPROPRIATE)

These questions are hypothetical and do not, in any way, represent any specific individual or group.

PRIMARY SCHOOL

You pass a classroom where the children are sitting in groups and working almost in silence from their mathematics/science or technology work books. There are worked examples of problems on the whiteboard. The teacher is sitting at the desk in the corner.

10. What would you say to this teacher?

SECONDARY SCHOOL

You pass a mathematics, science or technology classroom where the children are folding and cutting paper or building models [this question will ask each subject area separately; as well as for integrated STEM if applicable]. They are making quite a bit of noise talking to each other. Some are working at the interactive whiteboard. Others appear to be using their tablets. The teacher is walking around the class talking to the students.

11. What would you say to this teacher?

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CLASSROOM OBSERVATION SHEET

School ..... Date.....

KEY FEATURES OF THIS SCHOOL:

Any key features of the school which speak to the importance of STEM in the school and its culture of STEM.

.....

Teacher ..... Class .....

Subject ..... Year .....

Class .....

Observer..... Observation number .....

LENGTH OF LESSON ..... Topic .....

BRIEF DESCRIPTION OF LESSON:

.....

DESCRIBE MAIN FEATURES OF THE LESSON:

- STEM integration
- Collaboration
- Use of multiple representations
- Use of materials
- Realistic problems
- Links with personal experience
- Extent of student-centred instruction
- STEM dominant subject

GUIDING QUESTIONS FOR CLASSROOM OBSERVATION: ALIGNMENT OF SCHOOL/TEACHER WORK PROGRAMMES WITH THE APPROPRIATE LESSON CURRICULUM.

1. Does the lesson reflect the teacher's planning? How? (If you are able to view lesson plan)
2. Identify, if any, the proficiencies utilised in this lesson
3. What activities are used to develop students' deep understanding of STEM (or individual subject area)?
4. What was the focus of the lesson and how was this communicated to students?
5. How engaged were the students?
6. What assessment tasks were mentioned, foreshadowed or incorporated into the lesson?
7. How do teachers evaluate student capabilities?
8. How does the teacher convey standards to students?
9. Is the content of the lesson meaningful to students? Are connections made to life beyond school? (No, Sometimes, Yes)
10. What evidence of intellectual inquiry is there in the classroom?

FOLLOW UP QUESTIONS TO BE ASKED IN THE INTERVIEW:

Questions may emerge in regards the above features of the lesson, and in particular the influence of the school principal and school culture on STEM teaching and learning practice in the classroom.

NOTES FROM INTERVIEWS:

Interviews will be recorded and transcribed, but the interviewer may also identify issues that arise that s/he may want to note which were unexpected and/or require further thought and/or research and/or follow-up with the participant teacher or principal.

OTHER RESOURCES COLLECTED: FOR INSTANCE:

- Artefacts such as lesson plans;
- Curriculum (year, unit) planning documents;
- School planning documents;
- School marketing documents;
- Images of school – e.g. evidence of a culture of STEM

Principals as STEM Leaders (PASL) Building the Evidence Base for Improved STEM Learning

Case Study Focus Group questions (students)

The interviewer will adapt to different school circumstances by conducting a semi-structured focus group based on the following protocol.

STEM refers both to individual Science, Technology and Mathematics subject teaching as well as integrated models of STEM. Items referring to Engineering as a stand-alone discipline will not be included but treated as part of integrated STEM.

Before the focus group starts, please read the plain language statement to the students to ensure that they understand that they can leave at any time.

Start the recorder.

Go round the group and ask the student how they would like to be addressed (e.g., by their given name, nickname etc.).

STARTING QUESTION

What is the best thing about mathematics/science/technology/STEM in this school?

[Do you do mathematics/science/technology in groups, with your friends or mainly alone?

PROBLEM POSING

Here's an interesting STEM problem. Discuss how you might solve it. I have [relevant equipment e.g. calculators, rulers etc.].

[Use a grade-appropriate problem taken from an Australian resource]

Prompt with questions if the students get stuck.

What did you think of that problem?

Do you do many problems like that in your (maths/science/technology/STEM) classes or was this an unusual kind of task/problem?

FINISHING QUESTIONS

These questions are hypothetical. This means that the scenario is made up. Some of the questions might lead you to think about teachers you have or have had, but you should not name any teachers in your responses to the questions. If any names are mentioned the facilitator would remind you not to continue that comment but to restate your point, and to ignore what was previously said.

A visitor to your school might see a classroom where the children are sitting in groups and working almost in silence from their work books. There are worked examples of problems on the whiteboard. The teacher is sitting at the desk in the corner.

OR

A visitor might pass a mathematics, science or technology classroom where the children are folding and cutting paper or building models. They are making quite a bit of noise talking to each other. Some are working at the interactive whiteboard. Others appear to be using their tablets. The teacher is walking around the class talking to the students.

Which of these two classrooms do you experience at your school?

Which of these two classrooms do you think you learn best in?

Where do you usually get help with maths/science/technology?

Do you think you might like to do a job that involves STEM? Why/not? Tell me about what that might be?

Do you have any other comments about your experiences of maths/science/technology/STEM learning?

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Interview Questions – Case Study

***Please note:*

The interviewer will adapt to different circumstances by conducting a semi-structured interview based on the following protocol.

STEM refers both to individual Science, Technology and Mathematics subject teaching as well as integrated models of STEM. Items referring to Engineering as a stand-alone discipline will not be included but treated as part of integrated STEM.

RESEARCHER COPY

School/Institution .....

School/Institution # .....

Date..... Time.....

Participant .....

Interviewer.....

BACKGROUND

Personal background, nature of current role, length of time in their current role, prior experience e.g., other locations, other roles etc.

To what extent is STEM a focus of their work?

THE EDUCATIONAL CONTEXT

1. Can you describe some of the key issues STEM education?
2. What reforms have you implemented in an attempt to address these issues?
3. What key reforms at the system level have positively and/or negatively impacted on the teaching of STEM subjects and/or integrated STEM in schools?
4. What strategies have you used to disseminate reforms?
5. How have system-level reforms been received/responded to by schools? What impacts have they had?
6. How satisfied are you with these reforms overall?
7. Do you think the current curriculum, as it relates to STEM, provides a suitable framework for preparing students for their futures?
8. What would you like to be the key focus of your work in the next few years, as it pertains to STEM education?

CLASSROOM PRACTICE [IF APPLICABLE]

PEDAGOGY

We are trying to get a snap shot of STEM teaching in Australian schools and to identify any changes that have been taking place over the last 5 years or so.

9. Can you comment on what you believe to be important in terms of STEM pedagogy? Does the Department have a pedagogical framework? How is quality pedagogy understood and monitored in schools?

ASSESSMENT [IF APPLICABLE]

We are interested in current STEM assessment practices in schools.

10. How is mathematics/science/technology assessment approached in your schools?

11. Are there any issues or problems relating to assessment that you believe need to be addressed? (E.g. what forms of assessment as seen as more legitimate than others, what issues of in/equity arise in the types of assessment used, what issues of in/consistency arise within and beyond the school, are there any issues of misalignment between assessment, pedagogy and curriculum)?

12. How are these issues being addressed? (e.g. use of multiple assessment modes, monitoring of assessment, strategies to ensure comparability of standards)

13. What processes are in place to ensure comparability of teacher judgments/moderation?

CURRICULUM [IF APPLICABLE]

14. Do teachers have a good sense of what it is that they are expected to teach in each of the STEM disciplines separately and integrated STEM?

15. Do you think that the curriculum has become less or more conducive to STEM teaching (both single disciplines and integrated STEM) in the last few years? Why?

16. Do you think that transient students have more seamless movements between schools in terms of curriculum continuity than they have had in the past?

EQUITY

We are interested in how schools are able to help students who are not doing as well as they should be, particularly in relation to studying STEM subjects.

17. Without identifying specific individuals or schools, what is the situation regarding any such student groups in your state?

    Prompts:

    In what ways do specific practices and structures within schools (e.g. school climate, pedagogy, curriculum, relationships etc.) support or constrain issues of social/academic equity within the school?

18. In what ways is the issue of parental involvement in students' education being addressed in your state?

    Prompts:

    Has this been addressed as a problem?

19. What accountabilities/reporting requirements do schools have in relation to equity?

SCHOOL ENVIRONMENT [IF APPLICABLE]

20. Tell me about the leadership and decision-making processes and structures in schools. What are the implications of such processes in terms of the school climate? (e.g. teacher classroom practice and their relationships with others, parents/students)

21. Tell me about your thoughts on teacher professional development for STEM disciplines and/or integrated STEM.

    Prompts: How do teachers generally view PD and what are the implications?

    What opportunities are offered? How are they managed/ organised/ prioritised/ disseminated?

    What has been the impact of such opportunities in terms of the spread of improved practices? (E.g. Nature and extent of professional dialogue in the school

REPORTING [IF APPLICABLE]

22. How well do you think reporting procedures work in relation to STEM learning?

    Prompts: Do you think students understand what they are achieving in relation to what is expected of them (from report cards, other forms of reporting)?

    Do you think parents/guardians understand what is expected of their children, how their child is going, how they can help their child with their learning in STEM subjects?

Appendix C:
COVID-19 Context – Change to Research Design

Appendix C provides a summary of the impact of COVID-19 on the conduct of the PASL research project.

COVID-19 was an unexpected event which significantly impacted the PASL project processes and outcomes; specifically:

- It halted principal recruitment for participation in PL during 2020.
- PASL Directors engaged in reporting and scenario planning for possible COVID-19 impact on schools and negotiated these with the DESE team.
- At the outset, PL session delivery and data collection were paused.
- Subsequently, face-to-face PL and data collection were halted and replaced by online delivery of PL and data generation by telephone.
- Administration processes were increased and required revision on a daily basis.
- The proposed project timelines (work plan) were delayed.

Specifically, the revised high-level activities agreed with DESE, once the likely impact of COVID-19 was determined, included:

1. No new recruitment of principals or critical friends for Professional Learning (PL) participation will take place.

2. PASL PL will now only take place with principals who already confirmed to participate in the programme, and Programme 2 (P2) and Programme 3 (P3) will be the only focus.

3. Most effective and efficient PL rollout is being considered as principal attrition is mapped – with the potential of delivering PL across state borders via Zoom or other online platforms, if needed.

4. If required, feedback on P3 will be sought from principals via different channels (for example, through principal associations; targeting specific expertise).

5. The four PASL case studies already completed or nearing completion will suffice; unless:

    a. The Queensland special school is able to participate later in the year – which could mean a focus on principal and teacher interviews and artefacts, with no student involvement or classroom observation;
    b. The PASL Directors can quickly organise for a case study of the WA Department of Education's approach to the systematic and systemic support of STEM leadership in schools.

6. PASL has collected data across four case studies conducted in schools, and one which focussed on a system-wide approach to supporting STEM education. These will be published on the ASPA website in 2022.

7. PASL website development and resource quality assurance:

    a. ASPA will host the PASL modules and resources on their website with APPA and other organisations able to link to this site. Technical constraints will be communicated to preferred publishing partner.

    b. Directors have discussed publishing options with CSIRO (Mary Mulcahy) and are currently investigating with potential publishing partners.

    c. PASL is recruiting a marking officer to oversee this process.

8. PASL Reference Group (RG) could play a role in 'beta testing' the draft website and resources (under discussion with PASL RG Chairs and to align with RG TORs).

9. All PASL project team members have agreed to the Directors' suggestions in regards pivoting their expertise from a focus on PL delivery to ensuring the quality of PL programmes and modules.

10. Monitoring and evaluation of the programme under the leadership of Dr Gail Dennett will continue, with an additional question inserted in relation to the impact of COVID-19 on participation in PASL and in leading STEM in schools.

11. A new Service Delivery Plan will be developed and submitted to DESE end-May.

12. High-level timeline will be submitted to DESE end-April.

13. Revised budget records will be submitted to DESE when available by central UTAS finance as soon as possible following the submission of this report on June 3.

PASL

PRINCIPALS AS STEM LEADERS

PASL IS A CONSORTIUM LED BY THE UNIVERSITY OF TASMANIA.

The project is an initiative of and funded by the Department of Education, Skills and Employment (DESE).

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