Tech Schools as Mediating Organisations

for

STEAM Programs in Secondary Schools

Thesis submitted by

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Abstract

The Victorian Tech School initiative is an educational response to a political need for more STEM workers for the Fourth Industrial Revolution (4IR). Yet, the initiative requires a critical review of two assumptions. First, that STEM is sufficient to meet the personal, social and collective impacts of 4IR technologies. Second, that the current structure of mainstream schooling is relevant to the interconnected nature of industry and community in the twenty-first century. This research study examines these assumptions using a comparative case study on different ways that Tech Schools are mediating changes to education through community and industry projects. The impact on education by Tech Schools as "mediating organisations", is evaluated through four case studies on: constructivist programs and pedagogies in Tech Schools; the design and implementation of STEAM projects in schools; co-designing programs and competitions with industry; and types of support needed for teachers integrating interdisciplinary projects in their schools. Through cross-case analysis, the concept of Tech Schools as mediating organisations is solidified into stages of impact at a local school level through the development of an inter-institutional learning community (ILC) and at a broader level of education through reforms to the structure of curriculum, teaching and schooling. The main study finding is that integrated interdisciplinary project-based STEAM units, supported by Tech Schools provide an alternative model of education which could better prepare students for the 4IR by overcoming contradictions such as: the divide between the sciences, the humanities and the arts through STEAM; abstract versus applied knowledge through design thinking; student agency and a standard curriculum through authentic projects. Yet, Tech Schools cannot address these crises of mainstream education without structural changes to the system of schooling. This thesis is a provocation for Tech Schools to not only support schools but to positively disrupt the system of education.

Statement of Authorship

Except where reference is made in the text of the thesis, this thesis contains no material published elsewhere or extracted in whole or in part from a thesis accepted for the award of any other degree or diploma. No other person's work has been used without due acknowledgment in the main text of the thesis. This thesis has not been submitted for the award of any degree or diploma in any other tertiary institution.

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Chapter 1: Introduction

Context for the Study

Australian business is entering the Fourth Industrial Revolution (4IR). Robotics, 3D printing, artificial intelligence, drones, virtual and augmented realities, biotechnologies, new energies are just some of the new technologies which will not only impact on how we work, but also change the way we perceive, interact and modify the world we live in. Founder and Executive Chairman of the World Economic Forum, Klaus Schwab (2018) considers collaboration across diverse industry and community stakeholders to be a defining feature of the 4IR. Multi-stakeholder, interdisciplinary projects represent a social shift to the use of technology in industry.

This convergence of stakeholders through projects is a theme which runs throughout this thesis with a specific focus on the dialectical process of mediating between the *personal, social* and *collective* activities of stakeholders. The driving theme of this thesis is that this *multi-layered dialectical process* is replicable at: the societal level, through inter-institutional projects; the school level, through interdisciplinary projects; and the student learner level, through collaborative projects. "Tech Schools" could have a pivotal role as mediating organisations across each of these levels, allowing for a redesign of the education system to match current social-technological changes to industry.

This research study explored the impact of the social-technological shift to industry on education through an examination of new Tech Schools in Victoria and their role in supporting secondary schools to design and implement interdisciplinary STEAM projects. The central argument of the thesis is that technology-rich, interdisciplinary Tech School programs provide an alternative model of education which could better prepare students for social-technological changes to industry. Further, embedding Tech School projects into secondary schools could shift the outdated paradigm of mainstream education from teacher-led curriculum delivery in subject silos, to interdisciplinary student-led STEAM projects addressing authentic community and industry issues. First, the acronyms STEM and STEAM will be clarified as well as the political interest in this approach to education in Australia.

STEM assumptions reviewed.

Internationally and within Australia, education is changing in response to the automation of industry, artificial intelligence and the digitalisation of the workplace. A report by PricewaterhouseCoopers predicted that "44 per cent (5.1 million) of current Australian jobs, are at high risk of being affected by computerisation and technology over the next 20 years" (PwC, 2015, p. 4). In response to the impact of new technologies, the Victorian Government Tech School initiative was implemented as part of VicSTEM (State Government of Victoria Department of Education and Training, 2019c). This state-level program has been informed by the National STEM School Education initiative as a means of increasing student interest and performance in science, technology, engineering and mathematics (STEM) subjects (Educational Council, 2015). In Australian reports, these subjects are regarded as essential to careers in high economic growth industries positively affected by technology (Office of the Chief Scientist, 2016a).

A contentious term used to signify the systemic connection between government, education and economy is the "STEM pipeline" (Cannady, Greenwald, & Harris, 2014). Strengthening the STEM pipeline has been proposed in national reports as the solution to many education issues related to student and teacher engagement (Education Services Australia, 2018); work skills development (Office of the Chief Scientist, 2016a); innovation for the economy (Innovation and Science Australia, 2017); career pathways (PwC, 2015); school-industry engagement (Australian Industry Group, 2017); and improving performance on PISA and TIMSS tests (Caplan, Baxendale, Le Feuvre, & PwC, 2016). The assumed need for increasing STEM education in response to an industry crisis, is evidenced in this comment from the Victorian Government Department of Education and Training:

> Victoria is falling behind the world's top performers in STEM participation and achievement, and too many people still lack the skills required by a technology and knowledge-based economy. (2016, p. 1)

This view is shared internationally, with the STEM initiative gaining political and educational support since the early 2000s (Sanders, 2009). This educational focus on STEM – especially science and technology – is largely driven by global economic competitivity around the development and implementation of new technologies (Office of the Chief Scientist, 2013). International tests such as the Programme for International Student Assessment (PISA) and the Trends in International Mathematics and Science

Survey (TIMSS) present a trend of decreasing performance and participation in science and mathematics in countries such as America, Australia and many European countries compared to countries such as Korea, China, Finland and Singapore (Caplan et al., 2016; Marginson, Tytler, Freeman, & Roberts, 2013; OECD, 2010). Additionally, the lack of representation of women and people of colour led to STEM becoming a national focus since 2001 in America through the No Child Left Behind Act (Sanders, 2009, p. 22). Similar political campaigns have been implemented in other countries including Australia's National STEM School Education Strategy (Educational Council, 2015).

Despite the international attention on solving the STEM pipeline problem, there is no consensus as to the specific causes of disengagement in STEM subjects. Possible causes include stereotypes, gender and ethnicity inequalities, curriculum, pedagogy and the structure of education as a system (Allegrini, 2015; Henriksen, Dillon, & Ryder, 2015; Osborne, 2007; Tytler, 2007). The issue of STEM engagement is also problematic as STEM is an ill-defined acronym and concept (Siekmann, 2016). While the conceptualisation of STEM is open to debate, internationally the political and economic investment in STEM industries and education is substantial. Within Australia this is evidenced through copious reports by the Office of the Chief Scientist promoting the STEM initiative.

Beyond the political STEM rhetoric, certain assumptions need critical evaluation. These include: the compatibility of STEM education goals to increase innovation *and* test performance (Zhao, 2012a); the deeper social implications of technological change to the nature of work (T. J. Watson, 2017); the risk of reducing education to STEM career-readiness (Stokes, 2018) and whether current changes to education are adequate for preparing students for the global impacts of technology (Serdyukov, 2017). While each of the listed assumptions is examined in this thesis, it is the last point which was central to the research study: whether the current model of mainstream secondary schooling in Australia is adequate for preparing students for the global impacts of technology on work and society more broadly.

This thesis explores a range of new developments in education including interdisciplinary project-based learning using design thinking (A. Diefenthaler, L. Moorhead, S. Speicher, C. Bear, & D. Cerminaro, 2017); the integration of the arts and humanities in STEM to form STEAM (Burnard & Colucci-Gray, 2020; Taylor, 2016); co-design of learning programs with community and industry (Gatenby & Cantore, 2018);

and central to this thesis, the role of Tech Schools in mediating the introduction of these innovations into the structure of secondary schooling. While Tech Schools were part of a political initiative by the Victorian Government in Australia aimed at improving secondary student engagement with STEM industry, they also provided opportunities to examine an alternative model of education. It was the educational potential of Tech Schools to shift ingrained and potentially redundant structures of secondary schooling – such as teaching subjects in silos (Beane, 1995; Drake & Burns, 2004), standardised assessment (Wagner & Dintersmith, 2015) and transmission/lecture style pedagogies (Luna Scott & UNESCO, 2015) – which was the central focus of the thesis, as well as critically examining the enablers and constraints of making such a shift. These aspects of schooling have a political and a pedagogical dimension relevant to the philosophy (Noddings, 2015) and the sociology of education (Ballantine, Hammack, & Stuber, 2017) as well as Australian educational policy (Ministerial Council on Education, 2008). A brief description of the Tech School initiative is now provided and elaborated later in the thesis.

Tech Schools

The construction of 10 Tech Schools between 2017 and 2019 in Victoria represents a state government commitment to promote greater student engagement in the interdisciplinary field of STEM. A further objective of the Tech school initiative is fostering the development of twenty-first century enterprise skills, and an innovation mindset to encourage entrepreneurship (State Government of Victoria Department of Education and Training, 2019a). According to the latest Mitchell report by Lucas and Smith (2018) these capabilities are considered essential for this generation of workers who will need to be innovative and adaptable to rapid changes in employment.

The name “Tech Schools” can be confusing, as Tech Schools existed as part of the Australian education system from the 1960s-1990s (Jacks, 2016). Yet, *new* Tech Schools are less focussed on trade skills than design and digital technology skills, which reflects the digital shift in industry and the creation of new industries in Victoria (djpr.vic.gov.au/priority-industries-sectors). Further, Tech *Schools are not schools* in the traditional sense. They are a partnership between secondary schools, local industry and tertiary institutions such as TAFE or university. Secondary school students visit their local Tech school to engage in project-based learning modules ranging from single day-visits to 3-day projects. Tech school programs require students to problem-solve issues in priority industry sectors with high economic growth using cutting-edge technology. More information about Tech schools can be found on the Victorian Department of Education Tech School website https://www.education.vic.gov.au/about/programs/learningdev/techschools/Pages/default.aspx. Chapter 2 of this thesis summarises how Tech Schools design and deliver school programs, as well as other forms of education such as professional learning (PL), competitions and community engagement.

Case studies in Chapters 4 and 5 provide specific examples of Tech School engagement with schools. See also a published entry by the author on the disruptive potential of Tech Schools on education (Appendix H of this thesis) or online (Sacrez, 2020).

Comparable Models to Tech Schools.

To contextualise Tech Schools from a broader national and international perspective, three examples are provided of contemporary education organisations which are innovating program delivery and pedagogy.

1. Australian Science and Mathematics School (ASMS).

The ASMS opened in 2003 in South Australia, as an interdisciplinary senior-secondary school with a focus on science and mathematics. It can be regarded as a precursor to Tech Schools as an innovative learning environment hosted by a tertiary institution (Flinders University), utilising an interdisciplinary STEM curriculum targeting fields in “new sciences”, and emphasising capabilities such as self-directed learning (https://www.asms.sa.edu.au/#about).

The ASMS extends the potential influence of Tech Schools on mainstream education in providing a full-time alternative to traditional college education, while still meeting requirements of the Australian Curriculum and the ATAR system.

Research by Bissaker (2016) on the ASMS provides a valuable example of utilising affordances of a high-tech environment, which is applicable to Tech Schools. Her qualitative study addressed the relationship between “the physical learning space and the creation of a learning culture” in establishing the learning environment (2016, p. 126).

2. High Tech High (HTH).

HTH is a network of fourteen schools in San Diego focussed on promoting project-based learning combining science, technology and engineering with a liberal arts approach to learning. Valuing student diversity and providing student choice are fundamental to the HTH model, which aims to relate school to the real world of employment and community through authentic projects (Kluver & Rosenstock, 2003).

The collaborative, interdisciplinary project-based approach has been successful in engaging students from diverse cultural backgrounds with varying levels of academic ability. This has contributed to a sense of community and social cohesion between students who traditionally have been segregated (Kluver & Rosenstock, 2003). Further, project-based learning also increases engagement by helping students to see how their learning connects to the real world, especially when textbooks are substituted with internships (Murphy, 2004). Finally, by presenting student work for public viewing through digital portfolios on the school website and through public exhibitions, students have an authentic incentive for producing high quality work.

The HTH model provides a valuable example of embedding science, technology and engineering within a culture of social justice and art. Successful strategies developed over the 18 years that HTH has been operating, could inform curriculum design and pedagogical practices within Victoria's Tech Schools.

3. The Idea Translation Lab.

The Idea Translation Lab serves as the entry point into a series of art-science labs aimed at developing ideas through stages which explore their educational, cultural, humanitarian and commercial potential. David Edwards, the founder of the Lab network, states that the Idea Translation Lab aims to help students "learn to learn in real-world settings while pursuing dreams at frontiers of knowledge" (2010, p. 49). Edwards explains the learning process as student projects which begin as "seed ideas proposed by artists, designers, scientists, and entrepreneurs" which "evolve from there through student initiative and creativity into collaborative ventures in art or design, and offer some form of lasting implementation in society" (2010, p. 49).

The Artscience Lab has been run as an undergraduate course at Harvard, resulting in a number of successful innovations through its focus on creative experimentation which blurs the lines between art and science to address a real-world issue. Whether the ideas generated within this institution make it to the production or implementation stage is secondary to the rich learning which students partake in.

Similar to the Idea Translation Lab, Tech schools have the potential for developing student projects with real-world applications that cross the boundary between the arts and science, culminating in ideas with actual social and commercial potential.

Summary of alternate educational institutions.

The three examples provided demonstrate how internationally and within Australia, organisations similar to Tech Schools are starting from a different paradigm of education through the creation of an interdisciplinary curriculum, flexible timetabling, open-ended project-based units with connections to community, industry and external expertise. Although, the Tech school initiative has adopted a similar approach of starting outside of the mainstream schooling framework, it cannot function independently of mainstream schools. This creates a tension between supporting schools and disrupting the education system.

One commonality across these institutions, is their capacity to utilise STEM skills *in service of social issues*. This profoundly influences the perception of students, educators and communities that STEM can increase social equality as an empowering human endeavour. Yet, this capacity for curriculum to influence individual and community perceptions requires input from the arts and the humanities to transform STEM into STEAM.

Rationale for Research into Tech Schools

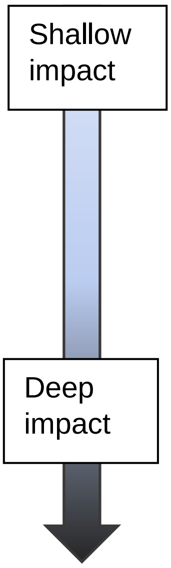
The construction of 10 Tech Schools in Victoria has served as a political solution to student participation in STEM as an addition to mainstream secondary schooling (State of Victoria Department of Education and Training, 2016). Yet, from an educational perspective, a need was identified for research into the potential of Tech Schools to *positively disrupt the system of secondary schooling*.

To what degree Tech Schools intended to disrupt the education system was an area which was unclear from statements by the Victorian Department of Education and Training (DET). For example, Tech Schools as excursion venues could initiate some student interest in science and technology. Yet, this would be a limited impact due to the short amount of time that students attended the facility. Further, there was the issue of *evaluating the quality of student learning* for project-based-programs run in Tech Schools. Evaluating quality was different to counting the number of students attending Tech Schools to meet a quota, which was one of the Key Performance Indicators (KPI) for each Tech School.

Professional learning (PL) for teachers on the design thinking process seemed to offer a greater impact in supporting project-based learning in schools. Yet, this required commitment by schools to *assimilate projects into their school structure*. How Tech Schools could mediate this radical change to schooling was identified as a central issue to be researched, as the literature indicated that innovating school structures was a widespread and long-standing challenge of education in Australia and overseas (Lucas, Claxton, & Spencer, 2013; Serdyukov, 2017; Wagner & Dintersmith, 2015; Zhao, 2012b). Further, while Tech School programs were not specifically designed to deliver against the curriculum, they were designed to increase student engagement in STEM and to develop twenty-first century entrepreneurial and enterprising capabilities. This suggested a need for *creating standards for a non-standard educational model*, as PISA and NAPLAN tests seemed unsuited to measuring the real-world learning outcomes of Tech School projects.

An additional research focus was the capacity for Tech Schools to mediate the connection between school and industry, which according to the literature was an issue for many schools (Australian Industry Group, 2017; Education Services Australia, 2018). Initial discussions with the Tech Schools Department suggested that Tech Schools could have a significant role in making *authentic school connections with industry* through the co-design of projects with industry; fostering relationships between teachers and industry representatives; and expanding learning beyond the school through authentic projects in the community.

The diverse range of activities which Tech Schools were undertaking sat within a scale of disruptive potential for education from a shallow impact to a deep impact, as shown in Figure 1.



1) Student engagement in Tech School programs and extra curricula activities

2) Supporting teachers to adopt new pedagogies through immersive professional development and resource sharing

3) Fostering community/industry involvement in the development of school projects

4) Promoting a reformation to the delivery of the curriculum from subject-based to interdisciplinary project-based learning in schools

Figure 1. Tech Schools' potential impact on education.

The potential impact of Tech Schools is explored further in Chapter 2 of the thesis through a review of literature on: the assessment of real-world capabilities by Lucas et al. (2013); the limitations to innovative learning by dividing knowledge into subjects (Wagner & Dintersmith, 2015); the undervaluation of the creative arts (Eisner, 2002) and the humanities (M. N. Smith, 2011) in the current STEM initiative; as well as a need for a paradigm shift in education away from the GERM "Global Education Reform Movement" to focus on local entrepreneurship and personal creativity (Zhao, 2012b, p. 3). These authors remind us that Tech Schools are part of an ongoing international discourse to reconcile antimonies involving the philosophical, political, institutional, economic, pedagogical and pragmatic nature of education in the twenty-first century.

Over the course of the research study these themes were synthesised into a developmental plan for deepening Tech Schools' impact on Australian education in stages, which is presented in Figure 10 of the Conclusion Chapter. These themes also informed the central research question and sub-questions.

Central Research Question and Sub-Questions

This research study examined the multiple impacts that Tech Schools could have on secondary STEAM education. This informed the main research question:

How can Tech Schools as mediating organisations promote student, teacher and school engagement in authentic STEAM projects?

To answer this question, the research study was divided into four sub-questions:

1. How do Tech School programs and pedagogies promote student engagement and growth of capabilities in STEAM?
2. How do Tech Schools support the development of new teacher pedagogies related to planning, teaching and evaluating STEAM projects?
3. How do Tech Schools mediate the relationship between schools, industry and community?
4. What are the enablers and constraints of embedding the Tech School model of STEAM learning into secondary schools?

Overview of the Study.

This was a mixed methods comparative case study of STEAM program design, pedagogy and implementation in Victorian Tech schools and secondary schools. Exploratory case studies were developed from two Tech Schools and two secondary schools. Observations of teaching, surveys and interviews with educators and students in Tech Schools and secondary schools were conducted to answer the research question. The study commenced in February 2018 and was completed in April 2021.

Predominant focus of case studies.

The case studies focussed on theoretical and empirical reasoning for effective Tech School program design and implementation, as well as the professional skills and conditions needed for school educators to effectively plan and implement STEAM units similar to Tech School programs. The study implications are aimed at promoting policy and structural changes to secondary schooling by addressing two levels of education: first in proposing *practical recommendations* for STEAM education practitioners such as secondary school teachers, Tech School educators and interdisciplinary program designers. Second, in evaluating the Tech School initiative from a theoretical constructivist perspective, and its potential for *supporting educational reforms* towards project-based learning which is relevant to principals, school leaders, education policy-makers such as the Department of Education and Training (DET) and curriculum designers such as the Australian Curriculum, Assessment and Reporting Authority (ACARA).

In this study, examining the relationship between pedagogy in secondary schools and Tech Schools – and the political and theoretical activities which inform them – is in keeping with a pragmatic-instrumentalist approach to research (Dewey, 1960). This political-pedagogical-theoretical tension underpins the conceptual framework, presented in Chapter 3 of this thesis. How these dimensions of the Tech School initiative informed the research methodology is described in Chapter 4.

Methodology

Research was undertaken through a comparative case study using a sequential exploratory mixed methods design (Kervin, Vialle, Howard, Herrington, & Okely, 2016). The reasoning behind using mixed methods was primarily for triangulating different forms of data for a more comprehensive understanding of the research problem than could be achieved through any single approach (Creswell, 2015). Further, the use of mixed methods allowed for the strategic interchanging between quantitative and qualitative data collection in the individual cases selected, to best answer the research question (Bazeley, 2018). In this way, the method developed sequentially, which suited the exploration of Tech Schools as an emergent phenomenon in education.

Table 1 presents the research design which developed progressively through primary analysis of data collected in individual case studies which informed the design of the subsequent case studies.

Table 1

Comparative Case Study Research Design

Case study description	Research method	Insight leading to next case study
1. Cross-case evaluation: Standard evaluation method developed, tested and used to compare program design and pedagogies in two Tech Schools. Generates multiple examples of successful constructivist pedagogies applicable to secondary schools.	Mixed methods (qual-quant): Observations across sites are analysed and synthesised. Program 1: 1 student survey: 20 students 1 student interview: 4 students 1 teacher interview: 1 school teacher 1 Tech School staff interview: 1 educator Program 2: 1 student survey: 18 students 1 teacher interview: 1 school teacher 2 Tech School staff interviews: 1 educator in each All data is triangulated with a standard evaluation of programs.	The design thinking process as a means of structuring authentic, engaging projects is noted as a strength. Time limits of the program and lack of integration into school learning are noted as limitations. Comparison with a school-based STEAM program informs case study 2.
2. School STEAM festival: Case study of a 4-day STEAM festival. Focus is on the constraints and affordances of secondary school STEAM.	Mixed methods (qual-quant): Observations over 4 days 1 student survey: 60 students 2 student interviews: 2 students in each 3 teacher interviews: 1 teacher in each All data is thematically analysed and related to the literature. Case study written as a journal article. Findings compared to case study 1.	Student agency and authentic learning are strengths. Possibilities for greater curriculum connections and industry connections are noted. The potential for Tech Schools to mediate school-industry partnerships is the focus of case study 3.
3. Industry engagement: Case study of industry involvement in co-design of programs and industry-Tech School competition for secondary schools.	Qualitative study: Observations of students in competitions and industry co-design workshop 1 industry interview: 5 representatives 1 teacher interview: 1 school teacher 1 student interview: 6 students Case study to be presented at the 2021 STEM Education Conference.	Interviews with school teacher and students suggests that embedding Tech School projects in school programs would be more impactful.
4. Educator perspectives: Case study of the opportunities and challenges of integrating Tech School STEAM projects in schools.	Qualitative study: Interviews with: 18 students, 12 teachers, 9 Tech School staff, 3 interdisciplinary school leaders and 5 industry professionals are thematically analysed using NVivo.	The current and future role of Tech Schools is reviewed based on a synthesis of findings from the four case studies. Findings and recommendations are shared with participating Tech School directors for discussion.

Limitations and Delimitations

Limitations of the study were that only two of the 10 Tech Schools were studied which limits generalisation across all Tech Schools. In addition, two large public secondary schools in a regional city of Victoria were studied. The findings are therefore typical of mainstream education in regional Victoria, which may not be indicative of schooling in a range of schools in Australia and internationally. This impacts on the generalisability of the findings to other secondary schools in Australia and internationally as well as diverse institutional settings running STEAM programs.

Comparison of programs across five Tech Schools had been planned for 2020. Due to COVID-19 restrictions, data could not be collected onsite as face-to-face programs were moved online. In response, the research study focussed on deeper analysis of the case studies already conducted. This included a second round of interviews with selected teachers and school leaders, to further explore key themes.

Research delimitations were that the study was focussed on STEAM pedagogy and program design. This was identified as an under-researched aspect of the Tech School initiative and other STEM schools (Morrison, Roth McDuffie, & French, 2015). While the construction of Tech Schools had been justified politically through government reports, the justification lacked theoretical and empirical research into the *educational value of the initiative*. To establish the educational merits of the Tech School initiative, research was focussed on the practice of teaching and learning in Tech Schools and their involvement in school-based programs. It was hypothesised that the success of the Tech School initiative would be most dependent on the experiences of students and teachers, which does not occur in principle, but as a social and cultural practice (Cole, 1996; Dewey, 1916/2010; Holland & Lave, 2009; L. Vygotsky, 1978). For this reason, a predominantly qualitative approach to data collection and analysis was chosen allowing for participant observations and interviews to inform the selection of case studies. Insights gained from cross-case analysis were then compared to the published aims of the Tech School initiative as well as education literature to evaluate *intended versus actual* impact of the initiative.

Generalisability

Generalising from case study research can be problematic. This is due to the situated and contextual nature of a case study which can involve small sample sizes of participants, as well as the use of qualitative data collection methods (Robert. E Stake, 1995). Yet, case study generalisability is possible according to R. K. Yin by explicating themes across cases through the use of a framework for "analytic generalization" (2013, p. 325). This approach to generalising themes from multiple cases was adopted in the research study through a three-part process:

1. Program evaluations utilised standardised tools for collecting and analysing observation data which was then triangulated with interview and survey data.
2. Findings from the four case studies underwent cross-case analysis using two analytical frameworks which related empirical findings to the conceptual framework. Both analytical frameworks had an identical structure, with emphasis on either pedagogical interactions or inter-institutional interactions.
3. A multi-layer conceptual framework related the case study analysis to broader themes from the literature on educational research and politics. This permitted localised findings on social practices in the cases to be related to broader sociological issues for generalisable conclusions.

A brief description of key theories used for the development of the frameworks is included later in this chapter, while a deconstruction of key themes is included in Chapter 2. Chapter 4: Methodology, provides a more comprehensive justification for the methods used to generalise from case study comparison and synthesis.

Validity

The validity of the research design and methods was tested using Riege's four design tests (2003). These are briefly addressed here and elaborated in Chapter 4:

- *Construct validity*: Reviewing the theoretical notion of *a mediating organisation* against empirical findings from the case studies, which was facilitated through the analytical frameworks (R. K. Yin, 2013).
- *Internal validity*: Prior to commencing data collection, a pilot study was undertaken to determine key activities of Tech Schools, the most relevant participants to interview and the most suitable methods for collecting data. A

mixed methods approach allowed for cross-checking between standardised evaluations and participant perspectives from interviews (Kervin et al., 2016).

- *External validity*: The analytical frameworks enabled a comparison and synthesis of findings between the specific case studies. The conceptual framework mediated between the local context of research and broader themes from the literature to generalise the research study findings. Authenticity of the overall research design and focus was reviewed through ongoing discussions with stakeholders in Tech School program meetings (Y. Lincoln, 1995).
- *Reliability*: Several evaluations were undertaken of secondary school and Tech School programs as an iterative cycle of verifying the data collection and analysis tools prior to commencing the final case studies and between the case studies (Morse, Barrett, Mayan, Olson, & Spiers, 2002).

Conceptual Framework

The conceptual framework is outlined briefly below and detailed in Chapter 3. The construct of the conceptual framework is *constructivism*. The purpose of the conceptual framework was to provide cohesion in the research procedures including conclusions and the contribution of study implications. The framework:

- Modelled relationships between related theories
- Explicated theories which have contributed to the design of the study
- Provided a theoretical basis for analysis

These applications of the conceptual framework are from Leshem and Trafford (2007). How the conceptual framework meets these conditions is explained in Chapter 3.

Why Constructivism (and Not Social Constructivism)?

The theoretical construct used in this research study encompasses a number of theories related by a core definition of constructivism, which is that knowledge emerges from the active construction of meaning through personal experience and social interaction with others. Constructivists argue that knowledge cannot be transmitted ready-made from teacher to learner, nor is it an objective feature of the world (Bodner, Klobuchar, & Geelan, 2001; Riegler, 2011). In constructivism, knowledge and meaning are personally and collaboratively constructed, and can be continuously re-constructed. Interdisciplinary project-based learning – like STEAM – is ideally suited to constructivist pedagogies as students collaborate over an extended period to understand real-world concepts without predetermined answers (Boy, 2013; K. Gross & Gross, 2016).

Theories which fit under the umbrella term "constructivism" utilised in this thesis are: John Dewey's pragmatic instrumentalist theory of progressive education (1964); George Herbert Mead's symbolic interactionism (Mead, 1934); Lev Vygotsky's socio-cultural theory (1978); Cultural-historical activity theory (CHAT) stemming from the work of Aleksei Leont'ev (1978) and elaborated through a number of contemporary theorists; Seymour Papert's constructionism(1993) and Paulo Freire's Critical pedagogy (1996). A table is included indicating how each of these theories was utilised in the research project.

Of these listed theorists, Dewey and Vygotsky were the two theorists who most influenced the theoretical orientation of this thesis. While both theorists placed emphasis on the social nature of learning, their constructivist theories have subsequently evolved in different ways (Glassman, 2001). In terms of pedagogy, Vygotsky's legacy in Russia has led to a focus on *instruction through the internalisation* of social activity using cultural artefacts (Carpay, 2016; Davydov & Kerr, 1995), while Dewey's followers have emphasised *learning through personal development* to create culture (Garrison, 2012; Pieratt, 2010). Within this thesis, both perspectives have influenced the development of the conceptual framework's focus on the dialectical interaction between learning and teaching in pedagogy.

In education, Dewey's and Vygotsky's theories are often labelled "social constructivism" (Postholm, 2008). In this thesis, the more general term "constructivism" is used to highlight the ways that political, technical, technological, bureaucratic and ideological structures in educational institutions (such as secondary schools and Tech Schools) shape social interactions. For example, the types of social learning interactions that occur in Tech School programs have been shaped politically by a focus on twenty first century enterprise skills as well as industry themes. The *social* becomes codified into specific skills such as *collaboration* and processes such as *project management*. In this context, pedagogy is partly a *technical construction*. Further, in considering the use of new technologies in Tech Schools such as 3D printing, laser-cutting, VR and AR, pedagogy becomes partly a *technological construction*. This raises ontological and epistemological questions related to the ways that technologies shape consciousness and learning (Papert, 1993).

Similarly, secondary school learning interactions are structured by the curriculum, the timetable, subjects and year levels. These organisational structures determine what is to be learned, how it is to be taught and by whom. Bureaucratic structures inform the division of time and space of learning, as well as a hierarchy of roles in the school (Schlechty, 2010). Thus, in the school context, pedagogy is partly a *bureaucratic construction* to manage the business of teaching, learning and assessment (Weber, 1983).

Finally, the *design thinking process* utilised in Tech School STEAM programs and participating secondary schools in this research study, has a mediating function in relating student learning to industry issues through authentic project-based practices. The "human-centred design" process used in Tech School projects reflects a different ideology of human industry, labour and learning (IDEO, 2011). From a critical-cultural perspective, Tech School learning programs are partly an *ideological construction* (Giroux, 2001).

To argue that these aspects of education are entirely *socially constructed* is, as Hacking (1999) notes, to stretch the concept of "social" beyond any theoretical meaning. As the research study was concerned with critically examining the relationship between social, technical, technological and institutional structures within the new learning environment of Tech Schools, the full breadth of the term *constructivism* is used in the thesis. Constructivism allowed for the local and situated case studies to be related to broader sociological considerations influencing Tech Schools and secondary schooling. These are organised into two levels in Table 2.

Table 2
Constructivist Theories Utilised in the Thesis

1. Pedagogy and learning theory: Learning, teaching and program design		
Research application	**Theorists**	**Key themes**
The relationship between learning and teaching in school programs	Progressive education (John Dewey)	Relating the curriculum to the personal experiences of learners as active participants
	Socialisation and the Self (George Herbert Mead)	Personal and social identity in group learning
	Socio-cultural learning (Lev Vygotsky)	Cultural tools dialectically mediate development. Internalisation of social interactions
	Constructionism (Seymour Papert)	Creating technologically immersive learning activities and environments
2. Politics and sociology: Transforming the institutions of education		
Research application	**Theorists**	**Key themes**
The relationship between schools, education and society	Critical pedagogy (Paulo Freire)	Highlighting how institutional practices manage knowledge as power
	Radical pedagogy (Henry Giroux)	Ideology and the hidden curriculum
	De-schooling society (Ivan Illich)	Transforming the structure of education
	Activity theory (Alexei Leont'ev)	Levels in activity systems. Collective learning
	Expansive learning (Yrjo Engeström)	Second generation activity theory
	Relational expertise (Anne Edwards)	Building shared knowledge between professions
	Communities of practice (Etienne Wenger)	Learning cultures, communities and institutions

The dialectic between politics and pedagogy in constructivism.

The distinction between politically and pedagogically orientated theories is not clear-cut, in that many of the cited theorists have examined the interaction between the pedagogical and political aspects of education. Paulo Freire rightly stated that all pedagogy is political. For example, how a "banking" model of pedagogy is used to oppress the socially disadvantaged (Freire, 1996, p. 46). This is relevant to discussions regarding curriculum and subject structures in school. For example, the low number of female students taking up STEM subjects in schools is an interrelation of political and pedagogical issues (Allegrini, 2015).

Distinguishing between political and pedagogical constructivism is intended to clarify which aspect of theory is mostly drawn-on in parts of this thesis. The dialectical relationship between the political and the pedagogical activity of Tech Schools underpins the conceptual framework which embeds the local context of Tech Schools into the broader sociological context of education. The impacts of institutional structures in secondary schools and Tech Schools – such as curriculum delivery – on student and teacher agency, is analysed in Chapter 2 using neo-Marxist theories such as critical theory (Giroux, 2001). These theories were used to explore the *political context* of Tech Schools which informed the design of the conceptual framework. At the local level of the case studies, the analytical frameworks relate to social and organisational theories such as expansive learning (Engeström, 2016), relational expertise (Anne Edwards, 2011) and communities of practice (E Wenger, 1999). These theories break down the social networks of interrelated activities and their tensions, which help to understand how schools can transform their *boundaries of practice* through interdisciplinary STEAM (Jho, Hong, & Song, 2016).

Pedagogically, the social context which supports the attainment of personal, relational and collective goals in Tech School programs is explored through Vygotsky's theories of *mediated development* (Blunden, 2017; L. Vygotsky, 1978) as well as cultural psychologists such as Bruner (1977) and Cole (1996). Dewey (1902/1971) and Mead (1934) play a central role in understanding the roles that teachers and students negotiate in *collaborative learning* contexts. Papert's constructionism draws attention to the concrete role that technology and other tools can play in developing an active environment for *making* (Harel & Papert, 1991).

In this research study, case studies 1 and 2 focussed on the dialectic between teaching and learning in pedagogy. In case studies 3 and 4, the dialectic between schooling and industry/community (society) predominated. Yet, it was the interaction between these political activities which constituted the central crux of this thesis and the conceptual framework to critically analyse it. The conceptual framework (Fig. 2) presents how Tech Schools mediate the *dialectical relationships* related to politics, pedagogy, theory and institutions in education. Each element of the conceptual framework, as well as their relationship is outlined in Chapter 3.

As previously noted, all education is an interaction between political and pedagogical activities. Yet, in the case of schools, this relationship is often hidden through the teachers' choice of curriculum, the design of their learning programs as well as the structural and cultural elements of the school (Desjardins, 2015). This thesis deduces that Tech Schools and their development and delivery of programs, explicitly embody this political-pedagogical dialectic. In this way, the conceptual framework has been conceived as a "double-dialectic" between the dialectic of learning and teaching (pedagogy) informed by research and the dialectic of school and industry (inter-institutional relations) informed by politics. The term "mediating organisation" has been developed to conceptualise Tech Schools as social-technical contexts to relate political motives to educational principles through industry practices.

What is a "Mediating Organisation"?

The term "mediating context" was originally used in this thesis to describe the emergent phenomenon of Tech Schools. Over the course of the research study, Tech Schools increasingly developed formal approaches to designing programs and interacting with schools and industries. Towards the end of the research study the term "context" was replaced with "organisation" as a clearer description of how Tech schools mediated between schools and industry.

"Mediating organisation" is a newly proposed term which builds from research in CHAT. A similar term from the literature is "intermediary organizations" by Honig (2016, pp. 21-22) and Mitra, Sanders, and Perkins (2010) to describe organisations which enable policy change in education. For this research study, the term "mediating" is used – rather than "intermediary" – to highlight that policy change involves critical tensions between conflicting political and pedagogical motives (Daniels, Lauder, & Porter, 2009). This conceptually reframes Tech Schools from being "in-between" organisations, to representing a dialectical resolution to the historically developing contradiction created by ideological conflicts between educational and industrial change. This is elaborated in Chapter 2: Literature Review.

Theoretically, the term "mediating" was explored by Lev Vygotsky in studying how artefacts and tools could mediate the actions of remembering and learning. Vygotsky's theory of *mediated action* and his use of the *dialectical method* built from Karl Marx's concepts of capital and labour as mediating factors in society (Fu, 1997). Marxism underpins numerous fields of research related to education, power, society and politics such as CHAT (Engeström, 2001); critical theorists of schooling and culture (Giroux, 2001); and class and pedagogy (Freire, 1985). While there are many other neo-Marxist theorists in the field of sociology and education (How, 2003), the theorists listed are directly relevant to this research study of pedagogy and institutional engagement. A common theme across neo-Marxist and critical theorists is that *mediation is a dialectical activity of reconciling opposing or contradictory perspectives*. For this reason, mediation is best known in legal practice, with a focus on resolving disputes (Cooks, 1995). Examining the notion of mediation across different social sectors provided background to how Tech Schools might act as *mediators* – rather than *translators* – of policy when tensions arose between stakeholders.

The original *mediating triangle of action* was developed by Lev Vygotsky and further elaborated by Alexei Leont'ev and later Yrjo Engeström through CHAT (Cole, 1996; A Edwards, 2011). A comprehensive explanation of Vygotsky's original mediating triangle and its development in this study as a "mediating organisation" model is provided in Chapter 3: Frameworks.

Vygotsky's mediating triangle informed the design of the conceptual framework, which was further developed into analytical frameworks and evaluation tools used to compare: pedagogy in different STEAM programs in Tech Schools; and types of institutional engagement in secondary schools. The evolution from conceptual to practical analysis tools was an important stage in determining why programs were successful based on theoretically justified criteria. In this way, theory served as an orientating tool for data analysis.

Definition of Terms

The term "authentic projects" is used extensively in this thesis as it encapsulates the focus of the research study on the qualitative difference between Tech School programs and mainstream school programs. The first part of the term: *authentic* is a significant aspect of constructivist learning theory. In this study authenticity has three interrelated meanings depending on the organisational level of learning. First, at a personal level, *authenticity* is central to theories of pedagogy by Dewey (1964) and Freire (1998). Authenticity in this sense is *existential* in describing the levels of agency and autonomy which learners and teachers have in education. Second, at a school level, L. Vygotsky (1978) and other sociocultural theorists such as Cole (1996) relate *authenticity* to learning as part of a *social community* established by its members. Third, the concept of *authenticity* is used by many constructivist theorists to describe progressive education that *relates to work and life* outside of school, often involving the collective application of knowledge in projects to solve problems (Daniels et al., 2009). Authenticity is thus used to describe three aspects of education: *the personal*, *the social* and *the collective*.

In the same way that the word "authentic" is used to describe multi-layered interactions, the word "project" applies to three levels of education. First, Tech School *projects* relate to *student learning* through engagement in the design thinking process. Second, the term *project* can describe how *teachers* are actively changing the structure of schooling such as developing interdisciplinary units. Third, the term *project* can be used to describe broader *changes to industry* and society related to the 4IR. "Authentic projects" encapsulate personal, social and collective learning across organisational levels which can be conceived of as a matrix:

Table 3
Authentic Projects as a Multi-Dimensional Construct

Organisational levels of *projects*	**Layers of *authenticity* in projects:**		
	Personal	Social	Collective
Student projects			
Teaching practices			
Function of education			

Other terms and acronyms used in this thesis.

- *ATAR*: Australian Tertiary Admission Rank is a number that positions one student relative to all other students in their age group for the purpose of admission to tertiary courses.
- *CHAT*: Cultural-historical activity theory is a theoretical frame for analysing the use of tools by humans (Subjects) to mediate goal-directed activity (Objects).
- *Constructivism*: A learning paradigm which states that knowledge is meaningfully constructed between people based on current and prior experiences in context.
- *Dialectic*: The resolution of conflicting perspectives or forces through synthesis by creating a mediating concept to establish a more unified theory.
- *Fourth Industrial Revolution*: Referred to as the 4IR in this thesis or industry 4.0. It is distinguished from the 3IR by the interconnection of internet with technologies ("internet of things/IoT"), which includes sensors, machine learning and automation ("smart technologies").
- *Interdisciplinary:* A project is embedded across disciplines/subjects in a school. Each subject contributes to the overall outcome of the project.
- *Inter-institutional:* Relationships between institutions such as education and industry. This relationship is centred on a common project or program.
- *Mainstream education*: Refers to the standard compulsory model of Australian secondary schooling involving aged grouping into Year levels and separate subjects taught in timetabled lessons. Use of the term in this thesis does not refer to the inclusion of students with special needs, known as "mainstreaming".
- *Mediating organisation*: An organisation which dialectically integrates activities between different stakeholders or institutions to create a new practice/context. Tech Schools are an example of a mediating organisation for integrating industry practices into schools through STEAM programs.
- *Mixed methods research*: An approach to research which integrates both quantitative and qualitative data into a single study.
- *NAPLAN*: The National Assessment Program – Literacy and Numeracy is an annual test administered to all Australian students in Year levels 3, 5, 7 and 9.
- *Project-based learning (PBL)*: a collaborative approach to inquiry or solving a complex real-world problem, with learning demonstrated through presentation

or construction. The project is run over an extended period of time, involving stages for completion.

- *STEM*: The cross-disciplinary field of education and industry combining science, technology, engineering and mathematics.
- *STEAM*: The cross-disciplinary field of education and industry combining science, technology, engineering, the arts (humanities and creative arts) & mathematics.
- *TAFE*: Tertiary and Further Education colleges in Australia providing courses with a predominantly vocational focus for work-related qualifications.
- *Transdisciplinary*: The integration of content from multiple subjects based on the requirements of a developing project.
- *Pedagogy*: The educational practice of teaching for learning, where the influence on the learner is studied as a theoretically justified method open to comparative evaluation across contexts.

The reader may note the use of capitalisation for the words “Subject” and “Object” in this thesis. This capitalisation related to Cultural-historical activity theory distinguishes between *Subject as a person* and subject as a school discipline. Similarly, *Object indicates and intended outcome or goal*, while object is a material thing.

Author’s Position

Education research to inform policy change, as part of the social sciences is normative in making a claim for systemic change (Carr, 2003). Within the context of this study, the claim being made is that Tech Schools have the potential to mediate *improvements* to schooling – and education more broadly – through interdisciplinary community/industry projects. While this claim is supported with theory from the literature and empirical findings, the claim cannot be purely objective as it reflects the author’s own research positionality. From a constructivist perspective it is the “trustworthiness” of the research which supports the claim, with *authenticity* and *fairness* serving as criteria for examining the researcher’s own positionality (Lincoln, 1995, p. 277). The researcher’s background which has informed this positionality is outlined with reference to its influence on the research study.

My interest in undertaking this study stemmed from my Honours research on “meaningful learning” in primary schools. My findings indicated that integrated project-based learning was valued by students and school teachers. Yet, according to the teachers: the constraints of block timetabling, standardised curriculum and an emphasis on transmission-style pedagogies minimised the adoption of integrated projects. This was an issue that I had also encountered in my experience as a primary school teacher. The Tech School initiative seemed to provide the affordances for meaningful student learning through integrated STEAM projects. This would enable me to examine closely the benefits and issues related to project-based learning and whether Tech Schools could overcome the constraints noted in my previous study.

An early review of the Tech School scoping documents and informal discussions with various stakeholders in the Tech School initiative, suggested a range of potential issues which made the initiative research worthy. These issues included the potential of top-down management not connecting with school practice; the focus on STEM for the economy as an overtly political agenda; the potential for packaged learning programs that suited media publicity rather than quality education; and finally, how the success of the Tech School initiative could be evaluated from an educational perspective. Thus, my mindset in commencing the project was a mix of curiosity and scepticism and I reserved my final evaluation of the Tech School initiative until after the analysis of data.

My final presentation of the study in this thesis may appear to be an endorsement of Tech Schools reflecting a personal bias towards integrated project-based programs. This potential for bias is one that I have been aware of and countered through the development of standardised evaluation tools, extensive interviewing of teachers, and returning to the original issues as a reference to critically analyse my findings. Thus, the final thesis presents Tech Schools as having the potential to address issues in education, with examples of success through case studies. The analysis of case studies also presents potential issues with the initiative itself.

Finally, my experience of observing Tech School projects and developing an appreciation of the perspectives of different stakeholders from interviews has hopefully resulted in a representation of the Tech School initiative which is *trustworthy:* through authentic data collection and a fair analysis of the data.

Structure of the Thesis

The thesis is structured in seven chapters. A brief description of the content of each chapter and the organising ideas is listed below:

Chapter 1-Introduction: has situated the research study within the broad political background contextualising the Tech School initiative. It has identified the research paradigm, relevant theorists, rationale and research questions. It has signposted the development of a conceptual framework as well as standardised tools for data collection and analysis.

Chapter 2-Literature Review: examines the political context for the Victorian Tech School initiative. It summarises current theories, research and debates regarding twenty-first century education including innovative pedagogies, interdisciplinary STEAM programs and school-industry partnerships. It outlines the principal ideas of constructivism, which underpins the conceptual framework and success criteria for evaluating constructivist pedagogies in Tech School programs.

Chapter 3-Frameworks: examines in-depth the development of the conceptual framework for studying Tech Schools as mediating organisations. It elaborates on Vygotsky's theory of mediated activity to analyse the dialectical interaction between politics and pedagogy. The conceptual framework is translated into two analytical frameworks which examine Tech School mediation of: programs and pedagogies; and school-industry partnerships. These frameworks are situated in relation to three contemporary social learning theories by Etienne Wenger, Anne Edwards and Yrjo Engeström.

Chapter 4-Methodology: presents the study's research design as a mixed methods comparative case study. The suitability of constructivism as the overarching paradigm for the research study is examined. The participating sites are described as well as the populations studied. The data collection methods and instruments are evaluated with respect to previous research and usage in the current study. The adaptation of the conceptual framework into two analytical frameworks is justified based their function for cross-case analysis.

Chapter 5-Results: presents the main research findings from the four case studies. Each case study addresses one of the research sub-questions in presenting a distinct form of mediation by Tech Schools. Each case study is structured to consider the context, results, mediating factors, emerging insights and the implications for the next case study. Quantitative and qualitative analysis are utilised for the triangulation of data as preliminary analysis allowing for cross-case analysis in Chapter 6.

Chapter 6-Analysis: compares the four case studies using two analytical frameworks for secondary analysis. Through cross-case analysis, emerging insights from the case studies are organised into themes, allowing for synthesis and discussion in Chapter 7. These themes clarify the role of Tech Schools as mediating organisations for: new pedagogies based on constructivist theory, inter-institutional learning communities (ILC) and potential restructures to the school system.

Chapter 7-Conclusion: utilises the conceptual framework to synthesise the cross-case analyses. The findings from this tertiary analysis are related to emergent themes from the literature review to answer the main research question. The disruptive potential of Tech Schools is considered as developing through four stages of increasing impact on the school system. Recommendations for Tech Schools mediating STEAM integration in schools are outlined as well as broader impacts on education.

Chapter Conclusion

This chapter introduced the topic of the research study. It described the political context for the Tech School initiative and specified critical issues to be examined. The need for considering the multiple impacts of Tech Schools on education as well as constraints on transforming school structures, informed the research question, sub-questions, rationale and aims of the study.

A mixed methods comparative case study research design was selected to take advantage of Tech Schools' capacity for collecting quantitative data and also for recording the unique qualitative experiences of the study participants. A conceptual framework was developed to examine the dialectical relationship between political and pedagogical activities in Tech Schools. A sequential, exploratory, mixed methods approach to research was used to increase the validity of the study through triangulation of data, the development of standardised data collection tools and analytical frameworks to increase the generalisability of findings.

A summary of how key constructivist theories frame the study was included from a progressive pedagogical perspective and a critical theoretical perspective. The utilisation and elaboration of Vygotsky's mediating triangle was identified as fundamental to all aspects of the study: from interpreting the literature; to designing the conceptual and analytic frameworks; and relating local activities of Tech Schools to sociological factors relevant to education in the 4IR.

An in-depth investigation into the political and pedagogical context for the Tech School initiative follows this chapter, interpreted through the lens of constructivist theory.

Chapter 2: Literature Review

Introduction

The Tech School initiative is a current state-level political intervention to improve student outcomes in STEM subjects, in response to the impact of technology on industry and employment. To study this multi-level and multi-layered initiative, a distinction is made between the *political motives* and the *educational principles* which underpin the Victorian Tech School initiative. Chapter 2 reviews literature through a critical-constructivist lens to critique education as a systematically organised social construct. The chapter is structured in two sections: Section 1 draws on critical theory for an analysis of the relationship between education, society and industrial development in the twenty-first century. Tech Schools are situated within the context of education for the Fourth Industrial Revolution (4IR) and the Australian STEM education strategy. Section 2 draws on constructivist education theory to explore four potential impacts of Tech Schools on secondary education in Victoria.

Section 1 is divided into three parts. Part 1 explores the *function of education* in relating industry and society. Changes to industry and education are examined, as well as the potential for technology to either support social causes or reinforce existing hegemonies. Part 2 critiques the Australian STEM education aims of: promoting STEM for innovation; increasing participation and performance in science and mathematics; and developing industry capabilities for an increasingly technologized society. In part 3, it is argued that a shift from STEM to STEAM is needed to overcome the current dichotomy between the sciences and the arts. In this thesis, issues raised in Section 1 are drawn upon in Chapter 7 to consider how Tech Schools can have a broader political impact on secondary education beyond fostering STEM skills.

Section 2 is divided into four parts to evaluate the *educational construct* of the Tech School model from a constructivist perspective. Four potential impacts of Tech Schools on education are outlined: (1) demonstrating how innovative environments for learning can engage students; (2) trialling STEAM program designs and constructivist pedagogies; (3) professional learning for teachers including connecting transdisciplinary projects to the curriculum; (4) fostering collaborations between school, industry and the community. Each of these impacts is examined with reference to literature on global developments in education. Insights from Section 2 informed the design of four case studies which highlight Tech School impacts, presented in Chapter 5: Results.

The chapter concludes by tying together the different aspects of Tech Schools as "mediating organisations." It is hypothesised that Tech School mediation can occur at a *local level* by supporting schools who are trialling project-based programs and at a *political level* by presenting an alternative model to mainstream education through authentic connections between school and society. Insights gained from reviewing the literature lead into the development of a conceptual framework and analytical frameworks for examining case study data in Chapter 3.

Section 1: The Social-Industrial Function of Education

Education serves many purposes. A few examples which are reflected in school curriculum and culture include: the development of individual personality and capability; the transmission of knowledge and values for citizenship; and vocational skills and knowledge to contribute to society and the economy. In this way, education supports the development of *personal*, *social* and *collective* capabilities of students. The degree with which each aspect of development is fostered has informed the theoretical, historical, political and cultural evolution of the Australian education system, which is visible in education documents such as the Melbourne Declaration on Educational Goals for Young Australians (Ministerial Council on Education, 2008). These three layers of student development – the personal, the social and the collective – are used in this review of the literature to consider how education is responding to changes in society related to the 4IR. This provides a context for Tech Schools as organisations mediating between the macro level changes to industry and education, and the local context of secondary schools where the Tech School programs are implemented.

The division of the literature review into two sections reflects: (1) the socio-political context of Tech Schools as part of an incentivisation of STEM employability skills for the economy; and (2) the potential for Tech Schools to radically restructure secondary schooling towards interdisciplinary project-based learning which connects with local community groups and industries. Dividing the chapter in two parts, allows for an examination of issues related to STEM education, and an evaluation of the disruptive potential of Tech Schools on school structures *as separate topics*. This is important because digital technologies and STEM are presented in many public documents – most notably by the Office of the Chief Scientist and PricewaterhouseCoopers (PwC) – as the innovative solution to complex issues such as student participation and performance without sufficiently examining alternative solutions to these educational issues (Caplan et al., 2016; Prinsley & Johnston, 2015). This political conflation of STEM and educational innovation makes it difficult to critique some negative aspects of the Tech School initiative without dismissing its positive aspects. For this reason, the proposed two-part structure and their subsections allows for criticisms and praise to be clearly directed.

Part 1- Critiquing Education in Response to the 4IR

The construction of 10 Tech Schools in Victoria represents a targeted financial investment in education with a political motive: increasing student engagement in STEM subjects as well as developing enterprise capabilities for innovation and entrepreneurship. These are considered fundamental to ensuring Australia's economic global competitivity and preparing students with skills for new types of employment (State Government of Victoria Department of Education and Training, 2019b). Comments made in June 2020, by the former Minister for Education in proposing fee cuts for STEM subjects while doubling course fees in the humanities suggests that from a political perspective incentivising STEM education to support industry seems to be a straightforward argument. "It's common sense. If Australia needs more educators, more health professionals and more engineers then we should incentivise students to pursue those careers" (Hon. Dan Tehan, as cited in Karp, 2020, 19 June). Yet, such a utilitarian view of higher education oversimplifies the relationship between industry and education. This relationship is not straightforward because education has a role in supporting society through citizenship, whereby changes to society also impact on industry (Tomlinson, 2013). An example is the rapid development of green industries in response to informed consumer demand (Bradfield-Moody & Nogrady, 2010).

The vocational and economic driver behind the Tech School initiative is part of an international discussion on how best to educate students for the 4IR (Cingel Bodinet, 2016; Doucet et al., 2018; Lucas et al., 2013; Luna Scott & UNESCO, 2015; Vieluf, Kaplan, Klieme, & Bayer, 2012; Wagner & Dintersmith, 2015; Zhao, 2012b). To understand how and why education is changing, requires contextualising the literature on education within a broader framework of industrial development. Within this context, education can be considered to serve a socio-technological function which changes in response to technological and societal development (OECD, 2001).

The Increasing Irrelevance of Mainstream Education in Light of the 4IR.

Education as a political response to technological developments in the 4IR has been dominated by the STEM initiative. Tech Schools are politically part of the *STEM skills narrative* as well as being *advocates for project-based learning*. These two faces of the Tech School initiative are introduced here in considering how the broad context of education could better respond to the disruption of the 4IR, which includes reviewing assumptions regarding what skills will be needed.

Taking a closer look at industry 4.0.

Building from Marx's critique of capitalist industry, theorists such as Marcuse (1964); Bourdieu (1990); Giroux (2001) and Bowles and Gintis (2002) criticised the connection between schooling and industry as being an exploitation of education. From this perspective, schooling was an institutional process of reproducing the stratification of class through a hidden curriculum to produce factory-ready labourers and their managers. Yet, these neo-Marxist theories require a review relative to the "new industries" of the 4IR (Rundle, 2014). This is fundamental to the Tech School initiative because its project-based programs are designed to foster connections between schooling and new industries. First, developments to industry are reviewed followed by an examination of how education is responding.

(i) Socio-technological innovations to industry overlooked in education. Global digital connectivity coupled with local physical production represents a social shift in the production-consumption chain. According to Rundle (2014) this could include system-wide change in the relationship between society and industry as the *production process becomes democratised* through access to affordable robotics, new materials, 3D printing and opensource software.

According to Zhao (2012b) through the automation of production, it has again become economically viable for an industry to build locally, especially if the necessary skills and capabilities to design and operate the technology can be sourced from a local pool of talent. Yet, the focus on building technology skills should also be coupled with a focus on rethinking the *social-technical structure* of industry and education towards flexibility, diversity, collaboration and interdisciplinarity. A historic example of social innovations to production is how Japan came to dominate the car manufacturing sector through the development of a local flexible production system based on "just-in-time" (JIT) manufacture (Law, 1991, p. 10). By developing semi-autonomous teams – each responsible for one aspect of the product's design – customisation and adaptability became features of the production process. Because each team became accountable for the quality of their work, *up-skilling* rather than down-skilling became the norm (Kaplinsky, 1989). Yet, education seems to have developed in the *opposite direction* towards standardisation through centralised control rather than autonomy and adaptability.

The example of automation demonstrates that technology only supports innovation if it is coupled with new social organisations of production and labour (Feenberg, 1991). This serves as a lesson in planning for the innovative use of digital technologies in education by focussing on creating *socially-orientated structural changes* to education. Rather than replicating in a digital-form the outdated production line model of mass-standardisation (the Fordist model), schools could promote *customised education pathways* that utilise *community and industry as a networked human resource of expertise* (the JIT model). Tech Schools could have a significant role in mediating a personalised, authentic, local, JIT model of education.

In summary, utilising a digital platform allows for global connectivity, while a distributed network of local production overcomes the issue of dependence on centralised control of material production (Bradfield-Moody & Nogrady, 2010). In this way, technology-driven industries are re-emerging in regional parts of Australia and offering exciting career pathways for young people in their own community (Loddon Campaspe Partnership, 2019). Tech Schools play an aspirational role in raising student awareness of local opportunities for work, entrepreneurship and creating new industries. Yet the focus on local industrial projects has not translated to education which is fixated on global standardised testing and competition. By focussing on STEM skills for global competitivity, Australian education seems to be missing the socio-technological restructure of industry 4.0, which provides a framework for innovation and a vast local resource of authentic learning for schools to utilise.

(ii) The crisis of inauthentic education.

Industry in the 4IR is utilising technology to redesign its production system by democratising the manufacturing process, focussing on sustainability and fostering a local approach to production through automation and interdisciplinarity.

Currently, these socio-technological innovations to industry have not transferred to schooling, which operates under a different institutional paradigm. One which seems isolated and outdated in having lost touch with authentic issues and developments in the local community (Lucas et al., 2013). Further, the key features of *interdisciplinary and inter-institutional projects* which define the 4IR, are absent from the school system. Australian education has imitated the American technocratic model whereby: curriculum has become centralised; the process of schooling is measured out in blocks of time with knowledge divided into specialised subject silos; student and teacher agency have decreased; evaluation of learning is externalised through international competition; and educational research and development (R & D) is not a valued aspect of the teaching practice due to school hierarchies (Deresiewicz, 2014; Zhao, 2012b, 2013).

Tech schools are part of a growing argument that the education system needs to keep pace with *current* shifts in industry practices (Australian Industry Group, 2015). For example, industry is increasingly investing in creating, maintaining and exploiting *knowledge to improve services and adapt to changing markets* (Nonaka, Toyama, & Konno, 2000). A revival of progressive education, centred around the *application of knowledge to collaboratively solve real-world problems* is gaining support overseas (Lucas et al., 2013) but more slowly in Australia. This reflects a new wave of constructivist theory in education for "the innovation era" (Wagner & Dintersmith, 2015).

A Revival of Constructivism is Needed to Broaden the Scope of Education.

Constructivist reforms to education have been discussed for over 100 years (Postholm, 2008). More recently, it provided the theoretical argument supporting the progressive education movement of the 1970s (J. S Bruner, 1996; Geelan, 1997). Yet, the social potential of constructivism did not fit with the dominant movement of global standardisation of curriculum and assessment (Zhao, 2013). Pasi Sahlberg, refers to the standardisation of curricula to fit international student tests as the GERM "Global Education Reform Movement" infecting education like a virus (Zhao, 2012b, p. 3). Arguments against the global standardisation of education are reminiscent of arguments against the standardisation of industry and mass production which have been replaced by more adaptive models such as Japan's "just-in-time" (JIT) model of car manufacture (Law, 1991, p. 10). The issue in education – and in industry – is that reducing autonomy and decision making *at the local level*, reduces adaptability and innovation of the *system as a whole*. As Bernstein notes, the standardised curriculum reifies the system of education through "collection codes" to institutionally control teachers' pedagogical practice (1973, p. 252). This automation of the learning-teaching process promotes mediocrity of teaching, as agency, initiative and ambiguity threaten the codified system of education.

Since the 1980s, constructivist approaches to teaching have been gradually replaced by direct teaching methods and standardised examinations as part of an outcomes-based movement in education in Australia and America (D. Smith, 2011). This was an attempt by the education system to respond to neo-liberalism in industry by mimicking international economic competitivity in the form of *achievement competitivity* for a "return on investment" (Deresiewicz, 2014, p. 77). Consequently, defining, measuring and teaching for achievement has had a narrowing effect on curriculum and assessment (Eisner, 2002). Because constructivist approaches to learning were ill-suited to prescribed outcomes and structured lesson plans, constructivist theory was not translated into a well-articulated model of pedagogy (Solomon, 1994).

A constructivist view of pedagogy.

Constructivism as a practical theory of teaching and learning has not been popular in many schools, despite being a dominant theoretical paradigm in education (Matthews, 1994). Schools may support principles of constructivism such as: student-directed learning, knowledge as a social construction and learning as an iterative process of reflecting on concrete experiences, yet, in practice adopt *transmission modes* of delivering content. According to Osborne, this is especially true of science as a school subject "where science is taught as dogma and not as a body of knowledge to be approached, discussed and evaluated" (2007, p. 182).

This apparent contradiction between constructivist theory and practice can be attributed to a number of factors from the literature such as: the difficulty of developing *standardised assessment* of student-directed learning (Osborne, 2007); teacher perceptions that *constructivism as an epistemology and as pedagogy are incompatible* (Jaworski, 1994, p. 29); that constructivist theories have not been simplified into *practical working tools* for teachers (E. Glasersfeld, 2001); and finally, that constructivism is a *relativist* approach to understanding. For example, that one person's world-view is as valid as another or that student conceptions are not mis-conceptions but "children's alternative frameworks" (Solomon, 1994, p. 10).

Addressing in detail each of the difficulties of applying constructivist principles as a pedagogical approach exceeds the scope of this review, yet some examination is provided in relation to schools in Victoria. The issues of integrating constructivism into mainstream schools can be grouped into two main pedagogical problems linked to how the Victorian Curriculum is taught. Tech Schools could address these problems by utilising the curriculum as a means to constructivist learning through projects.

(i) Pedagogy should not be the administration of curriculum.

Pedagogy has been described by the VCAA as "how students will be taught and supported to learn", with the curriculum defining "what it is that all students have the opportunity to learn as a result of their schooling" (Victorian Curriculum and Assessment Authority, 2015, p. 3). The issue here is that education is reduced to learning and teaching the curriculum. This makes *learning the curriculum the Object* of education with pedagogy being a means to that Object. Yet from a constructivist-project perspective it is the *student's development of capabilities which is the Object* of education and learning the curriculum is the means to that Object. Currently, there is confusion regarding what are the means and Objects of education. The confusion becomes obvious when employers are overwhelmed with applicants with technical knowledge but lacking "soft skills, capabilities, personal attributes and competencies" for business (Deloitte Access Economics, 2017, p. 5). Constructivist projects (such as Tech School programs) address this issue through an emphasis on developing capabilities through their *application*, rather than as *curriculum content* to be explicitly taught. Analytical framework 1 was designed to evaluate the Tech School project-based model according to constructivist principles.

(ii) Knowledge construction is different from a curriculum continuum.

Correlating what a student knows/understands with where they sit on the curriculum continuum is the standard method of assessing growth, yet the curriculum is taught within levels to students grouped by age. This creates two issues: first, correlating learning with age by dividing-up the continuum of learning into levels across subjects does not account for students' diverse personal learning profiles (Robinson, 2017). Second, correlating curriculum knowledge with educational life experiences is the antithesis of meaningful learning from a constructivist perspective.

The first issue can be addressed through school structures which allow for different progression pathways as recommended in the *Through Growth to Achievement* report (Department of Education and Training, 2018). The second issue is indicative of a fundamental epistemological difference between constructivist learning and the curriculum structure, which is harder to reconcile. For example, dividing content knowledge into a curriculum continuum is a logical system, yet a pedagogical problem arises from organising the *experience of learning* according to this abstracted artefact. Authentic learning interconnects *what* we know and *how* we know through experience (Dewey, 1902/1971, 1938/1997). Further, learning from a constructivist perspective is a psychological construction of meaning through "cognitive adaptation" which rarely follows a linear progression such as a curriculum continuum (Jean Piaget, 1976, p. 18).

While learning can be supported using *curriculum knowledge as a tool*, learning the curriculum is not equivalent to learning about and from life (Freire, 1994). Treating the curriculum as a total representation of knowledge is akin to mistaking the shadows projected in Plato's cave for the sunlit reality outside (Jowett, 2009). This a problem of confusing *curriculum knowledge* with *world knowledge*.

Industry Customises while Education Standardises.

The *social innovations* which revolutionised industry in Japan such as JIT production seem to be quite transferrable to education. These include: diversifying skills; fostering autonomy and accountability for workers; developing interdisciplinary, adaptable and flexible systems; and fostering an R & D culture on the shop floor. Yet, the trend in mainstream Australian secondary education is the reverse of this development.

Standardisation has only increased with international tests like PISA and TIMMS serving as benchmarks for excellence in education (Zhao, 2013). Calls by Caplan et al. (2016) for an increase in test performance through more mathematics lessons misses the point that innovation in education (or industry) does not emerge from finetuning each element of a perfectly oiled production line and reducing the agency of individuals. Innovation in industry and education comes from developing an adaptable system that promotes interdisciplinary teams with a comprehensive understanding of the entire system, to collaboratively review and reimagine the construction of the system (Serdyukov, 2017). This level of autonomy promoted in innovative industries for workers has not translated to autonomy of design and operational action for schools, teachers and students as this requires *radical social changes to the system of education*.

Summary of Part 1: Relating Education and Industry in the 4IR.

For education to play a meaningful role in shaping the future of society and industry, it must move beyond its current role of responding to technological change through skill development. It has been argued that Australian education is focussing on the superficial aspects of the 4IR such as developing STEM skills while overlooking the social-structural innovation to industry which is transferrable to schooling. This innovation would consist of an adaptable teaching and assessment structure composed of autonomous teams of teachers, students, industry and community members collaborating on interdisciplinary projects. This a dramatic shift from the current factory-model of schooling suited to the needs of the Second Industrial Revolution (2IR) not the 4IR (Robinson, 2017).

Industry 4.0 is experiencing a shift from standard mass-produced commodities using a global factory model which exports human labour, to a flexible tailored service which produces locally using automation. In response, education should reflect both the *technological* and the *social* changes in industry 4.0. This would require a shift from: (a) standardised learning programs delivered in a rigid timetable focussed on specialised marketable STEM skills, to (b) a flexible collaborative approach to interdisciplinary program development and implementation with a focus on fostering entrepreneurial capabilities through authentic project-based learning, and constructivist pedagogies (Zhao, 2012b). These structural changes reflect an *ideological shift in education* from skills-driven standardisation to project-driven personalisation.

Finally, in meeting the challenges and opportunities of the 4IR, education can serve a critical role in two ways. First, in helping students to make *meaningful connections to issues* in their local community and opportunities presented by local industry. Second, by holding industry accountable for its impact on communities through *critical reflection*. Through projects which are co-designed with industry and schools: industry can provide a *constructive* environment for students to apply their knowledge to material issues, while school provides a platform for *critical* reflection on the historical impact of industrial development.

Relating social and technological innovation through Tech Schools.

The Tech School initiative in Victoria reflects the move away from standardised curriculum to project-based learning using a design thinking process to solve industry and community problems. This has the potential to reframe education by transferring the socio-technological innovations from industry 4.0 to education through constructivist pedagogies and interdisciplinary programs. Yet, as the name "Tech School" suggests, the initiative also has the potential of overvaluing the impact of technology over the social-structural innovations which define an industrial revolution. Avoiding this error will require adopting what Feenberg (1991) calls a "critical theory of technology". This is explored further in part 2 of the literature review.

In conclusion, Tech Schools are an opportunity to positively disrupt the structure of schooling through socio-technological innovation. Yet, the political purpose for Tech Schools is the production of STEM graduates which fits the utilitarian model of schooling for employability skills (Tomlinson, 2018). In this way, Tech Schools embody a contradiction in their motives between a *holistic process* of education through authentic projects, and promoting specialised STEM skills as *marketable products* of education. This "STEM-ification" of education will now be critiqued with specific reference to Tech Schools.

Part 2: Tech Schools in Context of the Australian STEM Strategy.

The rationale for Tech Schools is part of a state and national political agenda for (i) promoting innovation in STEM fields, (ii) increasing student participation and performance in STEM which includes teacher training and (iii) developing STEM skills and general capabilities in response to employment change (Education Services Australia, 2018; Office of the Chief Scientist, 2016a; State of Victoria Department of Education and Training, 2016). Tech Schools explicitly focus on developing students' employability skills relevant to growing industries and promoting a STEM career pathway (State Government of Victoria Department of Education and Training, 2019a). From this perspective, Tech Schools can be seen as a direct application of the STEM education strategy. Yet, they could also be a way to *reframe the STEM strategy* towards a more holistic goal of connecting schooling with industry and community, as well as student interests.

Tech Schools seem to be a merge between politically orientated STEM goals and constructivist education theory which reflects are conflicted rationale. This tension is part of the dialectical nature of Tech Schools which mediate between the economic, political and social aims of education. The three overarching educational goals of the STEM strategy will now be reviewed, as certain assumptions require critical examination to better understand the rationale for Tech Schools.

(i) Innovating education is not just a matter of promoting STEM.

Tech Schools are part of a national strategy to improve Australia's global prosperity through increased *innovation in STEM fields* (State of Victoria, 2016). Yet, education in the national interest, is a motive which draws upon contested beliefs of the philosophical and political purpose of education (J. S Bruner, 1996).

The reverse engineering of education to channel students towards specialised STEM careers is still a main agenda of Australian education as evidenced by the use of the "STEM Pipeline" strategy promoted in national reports (Australian Industry Group, 2015, pp. 5, 10; Caplan et al., 2016, pp. 5, 17, 20; Marginson et al., 2013, p. 51; Office of the Chief Scientist, 2014, pp. 20,21,23; 2015, pp. 1, 7; PwC, 2015, p. 16). The current discourse around STEM – and to a lesser degree the *capabilities* from the Australian and Victorian curriculum – are a continuation of neo-liberalism in education in marketing professional career skills to support the state through a skilled workforce (Desjardins, 2015). Yet, to carve off STEM as a portion of education and raise its status above other disciplines based on economic advantages, is to risk a return to schooling as the systemic stratification of students into different social classes (Bowles & Gintis, 2002). While STEM can be disputed from an equity perspective, it can also be disputed from an economic perspective. This contradicts the prevailing rhetoric in many Australian STEM reports that STEM underpins innovation for the economy.

The PwC, *A Smart Move* STEM report states "Australia needs a workforce that is technologically savvy and able to innovate. And one of the best ways to do this is by improving capabilities in STEM" (2015, p. 13). The Office of the Chief Scientist states "The relationship between STEM skills, innovation and competitiveness is well documented" (2016, p. 4). Determining whether STEM does lead to prosperity through innovation, and whether this should be an educational priority, initially requires defining what is meant by the term "innovation", as these reports do not provide a definition.

The *Australian Innovation System Report*, states that innovation is "about the implementation of novel ideas" with the intention of increasing value as a business strategy (Office of the Chief Economist, 2017, p. 6). This is achieved through the introduction of new products or processes, to increase productivity, effectiveness and efficiency of organisational and production systems with novel ideas *emerging from and applicable to any field*. Elaborating on this, the *Oslo Manual* released by the OECD and

Eurostat (2005) distinguishes between four types of innovation: product innovations, process innovations, marketing innovations, and organisational innovations. Some aspects of innovation for improving production processes seem well-suited to advancements in technology such as the automation of labour in manufacturing. Engineering seems foundational to product innovation – especially in manufacturing. Yet other aspects of innovation benefit as much from the humanities, arts and social sciences (HASS). Examples include: drawing on history to better understand materials (Acord, Jones, & Gillespie, 2015); the role of international politics and cultural studies for collaborating with foreign businesses and researchers (Cahill, Fitzgerald, Brass, & Parolin, 2015, p. 19); art and design for generating novel ideas (Maeda, 2017) and then marketing them (Cunningham, 2018, March 22). Therefore, the argument of "STEM for innovation" might just as well be made for "HASS for innovation".

Technological skills will be needed for innovation in the future, particularly for production processes in the manufacturing industry, yet innovation is not *attributable* to STEM skills. Further, according to technology innovator and former President of the Rhode Island School of Design (RISD) John Maeda, "We seem to be stuck in a kind of technology loop" where "we are supposed to feel like we are enjoying incredible progress. But it seems the tricks are exactly the same each time around the loop" (2010). Maeda considers art and design through human interaction with natural materials as central to promoting "critical thinking—critical making". From this perspective, investing in the arts and design would be just as beneficial to Australia's innovation economy, as investing in STEM.

STEM is a powerful instrument to support innovation through *improved tools and processes* (Innovation and Science Australia, 2017). Yet, engagement in the arts and the humanities provides new *sources of inspiration*. The inclusion of the arts and humanities in the STEM initiative for innovation necessitates a paradigm shift from STEM to STEAM (Maeda, 2017). This reflects a positive shift for Tech Schools who are developing STEAM programs to promote greater interdisciplinarity.

(ii) Increasing participation and performance in STEM is not a "pipeline problem."

According to national STEM education reports, the need to increase participation and performance in STEM subjects is an educational priority (Education Services Australia, 2018; Educational Council, 2015; State of Victoria Department of Education and Training, 2016). Yet, the issue of decreasing *participation* and decreasing *performance* do not necessarily have a common cause or a common solution. Potentially, an overemphasis on *improving STEM performance* on standardised testing for international comparison could be *one of the causes* of decreasing STEM participation as it narrows learning to fit test parameters. For this reason, the issue of participation and the issue of performance are examined separately.

Participation is a multi-dimensional issue.

Decreasing participation in mathematics and science is an international problem receiving significant research, particularly in secondary and tertiary educational settings (Henriksen et al., 2015). Factors related to the decrease are diverse, with studies citing the following as relevant: the importance of student *identity formation* (Bøe & Henriksen, 2015; Holmegaard, Ulriksen, & Madsen, 2015); the influence of *stereotypes*, particularly the influence of *gender* and *ethnicity* (Allegrini, 2015); changes in the *education system* and *curriculum* (Lyons & Quinn, 2015); uninspiring *pedagogy* (Osborne, 2007); and broader social attitudes towards the benefits of STEM as part of *national culture* (Ryder, Ulriksen, & Bøe, 2015). Across these studies there does not seem to be any factor that is a single cause of decreasing participation. Depending on the particular context, some issues predominate, and in many cases a mix of interrelated factors contributes to disengagement.

A lack of gender equity in STEM professions is a common theme mentioned across national and international STEM reports, yet even this issue is multi-layered with feminist perspectives demonstrating that generalising the STEM-gender imbalance does not account for compounding factors such as stereotypes, socio-economic status and diversity of interest (Archer & DeWitt, 2015; Løken, 2015). For this reason, any simple explanation, particularly if it is used for developing a systematic intervention, may not sufficiently account for local factors such as the type of students, community values, or the school culture (Osborne, 2007; Sjøberg & Schreiner, 2005; Tytler, 2007). As STEM education has made gender inclusivity a focus of its campaign, further examination of the issue is now presented in terms of equity.

Equity goes beyond promoting equal STEM opportunity.

Internationally gender inequality is still prevalent in STEM employment and education (Allegrini, 2015). Within Australia, the Office of the Chief Scientist (2016a) released its STEM workforce report. Examples of gender inequality from the report include:

- "In 2011, 84 per cent of people with a STEM qualification were male." "The field with the most uneven gender distribution was Engineering, at 93 per cent males." (p. 12).
- "The most common industry of employment for STEM-qualified people was in Manufacturing, followed by Professional, Scientific and Technical Services, and Construction" (p. 20).
- "There was almost three times the percentage of male STEM graduates in the highest income bracket ($104 000 or above) compared to female STEM graduates." (p. 36)

These statistics indicate a problem with STEM. Yet, the solution to the problem as proposed in national reports is to encourage more females to take on STEM education and STEM employment pathways. In this way, the problem of *inequality* in STEM is shifted to the political problem of getting girls in STEM and how to *funnel* as many of them into the STEM pipeline through education (Cannady et al., 2014). The "STEM equality problem" becomes reframed as the "Women in STEM problem" without questioning the relationship between STEM and industrialism from broader social and feminist perspectives. Manufacturing, professionalisation, science and technology, engineering and construction historically reflect a distinctly male perspective of domination over nature and women (Littig, 2001).

It is important that women should have an equal share of opportunity and earnings in STEM fields as an immediate and concrete right. As Dr Finkel notes, the pay gap between men and women "is longstanding and it is unacceptable" (Office of the Chief Scientist, 2016a, p. iii). Yet, Finkel's statement that "No clever country under-serves half its people" is one-dimensional in being a quantitative notion of gender equality. It reflects a belief that while all Australians should be served an equal portion, they should still be served from the same dish of opportunity: STEM. A *multi-dimensional* view of equality values diverse ontologies which do not fit within the STEM paradigm (Greene, 1978). To pay men and women equally but value one type of knowledge/work (STEM) over others may promote *equality*, but to value diverse knowledge and work which different types of people contribute represents *liberty* (Carr, 2003). Within a democratic conception of education for employment, the STEM problem may need to address the issue of equal opportunity in STEM first, but it also needs to address the issue of valuing diverse professions which creates opportunities beyond STEM. This issue is indicative of the broader tension between personal, social and collective conceptions of valuable work and education which run through this thesis.

Participation in science through industry: Engagement and critique.

The Australian STEM initiative has sought to increase participation in STEM through partnerships with industry. Tech Schools have been constructed as a direct approach to fostering this partnership with a *vocational emphasis*. Whether an increased relationship between education and industry will have any significant impact on student participation in STEM careers is an assumption which will need to be evaluated over time. According to Tytler (2007, p. 19), secondary school science has an "economic purpose", yet it also has a "cultural purpose, a democratic purpose, a utilitarian purpose and a personal-development purpose". This suggests that Tech Schools have the potential for utilising multiple interacting pathways beyond vocationalism for promoting engagement in science.

Tech Schools' attention to the humanistic value of aesthetics, human-centred design and social impacts through the incorporation of arts and humanities in STEAM may provide a cultural counterpoint to the economically driven "STEM enterprise" (Office of the Chief Scientist, 2013, p. 12). A detailed examination of Tech School STEAM programs for student engagement is provided in Chapter 5.

Finally, promoting humanism in STEM not only supports personal consciousness for development, it supports a global consciousness of the impact of capitalist development. Claims by the Office of the Chief Scientist that STEM is the driver for industry and economic prosperity, should be balanced against the social cost of industry. This has been overlooked in the economic hype for *STEM*:

> "When I look to that future, I see a world of opportunity for Australians with STEM training. I see a STEM-powered economy that Australians can forge, if we have the confidence and the capability combined." (Alan Finkel AO Australia's Chief Scientist, 2016, Foreword iii).

This nationalistic sentiment needs to be considered in terms of education for *global citizenship*. National prosperity through STEM could increase global inequality if it is not coupled to a responsibility to address global social issues such as poverty, hunger and a lack of basic technologies such as electricity (Schwab, 2018). Education has a responsibility to not only promote learning in STEM, but to ensure that this knowledge and these skills are utilised for the betterment of humanity, beyond meeting the needs of any single consumer, any single industry or any single nation.

To promote *STEM education for emancipation*, a critique of technological progress should be included. This requires teachers and students to ask: What is the social problem being solved – or created – by certain technologies? (De Lissovoy, 2010). A contemporary example of this critical awareness coupled with social action can be seen in international student protests led by Swedish teenager Greta Thunberg regarding global warming (Watt, 2019). This political activism by students demonstrates how social awareness can influence economic investment into renewable energy and its technological requirements. Encouraging students to actively engage with politics on their own terms should be undertaken as part of a democratic system of education, rather than outside of it.

Standardised performance as a misdirected notion of quality learning.

Australia's declining performance on international mathematics and science assessments such as PISA and TIMSS, has been noted as requiring systemic intervention, across most Australian STEM reports. Within Australia, the cause of this decline has been attributed to: lowered standards for teachers in primary and secondary schools (Caplan et al., 2016; Prinsley & Johnston, 2015); students selecting less challenging mathematics and science subjects to improve ATAR scores (Education Services Australia, 2018); university courses reducing mathematics and science prerequisites (Lyons & Quinn, 2015); and a lack of time dedicated to teaching mathematics and science (Australian Industry Group, 2015; Caplan et al., 2016; Education Services Australia, 2018). Similar to the issue of decreasing participation, decreasing performance is multifaceted, which indicates both a need for diverse strategies as well as a coordinated and balanced response. To date, the proposals presented for improving STEM performance have lacked balance, with a number of reductionist recommendations for education being endorsed.

The *Making STEM a Primary Priority* report, by PwC is an example of the growing rhetoric around reversing the "STEM-stagnation" affecting Australia's economic growth (Caplan et al., 2016, p. 11). The report states "The primary curriculum has been burdened with 'extras' such as drugs, healthy food, racism, environmental concerns, weed identification, driver education and stranger danger" (Caplan et al., 2016, p. 26). Yet, from a constructivist perspective, these social topics are *not a distraction* from mathematics and science, but *a context* for embedding mathematics and science within real-life experiences (Dewey, 1938/1997). For example, "healthy food" as a topic is rich in learning about: energy sources; metabolism; fats; sugars; carbohydrates; the measurement of joules, grams, kilograms; health statistics; and the cost of different foods. Mathematics and science taught in context of students' personal experiences as well as societal issues are engaging, result in deep learning and promote interest in diverse professions (Sullivan, 2011; Tytler, 2007). Thus, establishing a clearer social purpose for the application of science and mathematics may increase student motivation to learn, resulting in greater participation as a prerequisite to improved performance.

The report by PwC typifies the ambiguous argument by politicians for a "back-to-basics" approach to education which seems out of step with industry and society's increasing diversity and complexity (Barnes, 2020, July 27; Hunter, 2019, December 9). This mismatch between industrial and educational developments was outlined in part 1 of the literature review. The issue of a cluttered curriculum or burdensome extras, potentially has more to do with the *way that the content is organised* than the content itself. It reflects a lack of innovative thinking at a program-design level with regards to integrating the curriculum (Beane, 1995). For this reason, project-based learning can be a more efficient and engaging model of education by flexibly adapting the curriculum to meet a range of complex and diverse topics, thereby reducing the amount of revision and testing of separate content (Kanter, 2010). Rather than going back to basics, education needs to improve its capacity to develop programs that are as rich and complex as contemporary life and work.

Reframing the notion of performance.

Performance on a standardised test focusses on the ability to carry out specific steps in a sequence to achieve a measurable outcome. This is a deterministic view of performance and success as a closed loop. Performance as the perfect repetition of predetermined actions – whether it be in mathematics, dance or technology – is a form of *mechanics*. This knowledge has a high level of redundancy as automation is the endpoint of physical and cognitive automaticity of mechanical performance (Senge, 2012).

Up until the advancement of electronics in the 1970s, a "computer" was a person whose primary role was performing repetitious calculations perfectly (Grier, 2005). Outside of mathematics, parallel tasks included transcription, copying, stenography and bookkeeping by human scribes. These are redundant professions as this type of performance is becoming automated (Schwab, 2018). This does not mean that mathematics and literacy become obsolete. Yet, it does require a reframing of what type of performance is worth testing (Zhao, 2012a). This is resulting in a shift in the type of questions asked on PISA tests to focus on collaborative problem-solving (OECD, 2017) and creativity (Lucas, Claxton, & spencer, 2015).

Non-automatic performance is seen in real life tasks which focus on the ability to choose from a range of possible processes to solve a problem or explore an issue. It is *context-dependent* with success measured on how well knowledge and skill are applied to solve a problem or to generate new knowledge (Lucas et al., 2013). Whether a practitioner has manually, mechanically or digitally performed a task is less important than the outcome of performance based on its applicability. Thus, the issue of performance noted in STEM reports is misdirected. The *issue of performance* should not be directed at student performance on standardised tests but the *relevance of tests* that measure performances which will become obsolete through automation.

Analysing this issue exceeds the scope of this review of the literature, yet, according to Education Services Australia (2018) there is a need to have a broad representation of STEM knowledge beyond test scores, which includes examples of knowledge and capabilities applied to real world industry problems. Further, research by Zhao (2012a) indicates a need to clarify whether excellence on examinations is a reliable indicator of innovation and entrepreneurialism.

In summary, decreasing student participation and performance in STEM subjects are symptoms of diverse causes, requiring a cautious and open-minded response. As increased participation in STEM has political ramifications, vocational and economic advantages are presented as *extrinsic incentives* to attract and motivate students (Office of the Chief Scientist, 2016a). Yet, motivation is also influenced by an *intrinsic need* for developing an identity in response to social and cultural values. Increasing participation in STEM subjects as an aim of Tech Schools, may require a more holistic approach to motivation by supporting students' higher psychological learning-needs for self-actualisation and active contribution to a social cause (Maslow, 1970). Tech Schools provide a context for learning where improving *performance is a means to a broader purpose*, which is solving real-world problems (Lucas et al., 2013). This can serve as a model for education reforms by emphasising authentic and purposeful learning. Projects can serve as a means of motivating students to engage with challenging academic material as a pathway towards addressing societal challenges and opportunities.

(iii) STEM skills and general capabilities should not be conflated.

Use of the acronym STEM in diverse contexts, without explicitly addressing the meaning of STEM, has led to the *political branding* of education and work. A few examples from reports by the Office of the Chief Scientist include "STEM skills", "STEM graduates", "STEM workforce", "STEM fields", "STEM worker", "STEM literacy", "STEM capable", "STEM enterprise", "STEM pipeline" and "STEM endeavour". Cryptic comments by Australia's Chief Scientist such as "As time moves on it becomes increasingly difficult to decide who is and isn't a 'STEM worker", further mystify the use of the STEM brand (Office of the Chief Scientist, 2016a, p. iii).

To simplify the matter, the Australian industry Group "has emphasised from the outset that the acronym STEM is not a jobs descriptor. It should only be used in the context of skills" (2017, p. 13). This seems straightforward except that "STEM skills" are said to foster "deep knowledge of a subject, creativity, problem solving, critical thinking and communication skills" (Office of the Chief Scientist, 2016a, p. 3). Yet, these are *general capabilities* which can be fostered in any other field of knowledge such as the arts and the humanities.

Education Services Australia provide a comprehensive definition of STEM skills as:

> Skills and capabilities developed directly through the study of the disciplines of science, technology, engineering and mathematics. They include skills such as applying the scientific method, specific discipline knowledge, theoretical understanding, and data analysis utilising formulas and models (2018, p. 19).

According to Siekmann (2016) the indiscriminate use of the acronym STEM is a major impediment to the research, policy implementation and the practice of STEM education programs. Siekmann adds "Our preference is to use STEM only as any other acronym - an abbreviation of words, without adding any further meaning to it" (2016, p. 11). Yet, the politically neutral definitions of STEM provided by Siekmann and Education

Services Australia do not account for the cross-disciplinary nature of STEM as a synthesis of knowledge between fields, which reduces the radical potential for innovating the delivery of the curriculum from subject-based to project-based.

In summary, from the perspective of promoting democracy in education, it is important that the STEM acronym should not become an *ideologically driven method of sorting and labelling people* into STEM versus non-STEM. Reports from the Office of the Chief Scientist exemplify the creation of this false dichotomy based on STEM qualification. The STEM/non-STEM distinction is then used to make connections between demographics, income and employment status, which implicitly promotes broader discriminations of value between members of society (2016a, pp. 5, 10, 12).

Summary of Part 2: Tech Schools as part of the national STEM initiative.

The Tech school initiative is founded on aims to increase the employability skills of students in high-growth industries in response to the influence of technology on the contemporary workplace. This rationale for Tech Schools is part of a national educational agenda for developing STEM capabilities in reaction to employment change, increasing student participation and performance in STEM subjects, and promoting innovation in STEM fields.

Tech Schools have an influential role as part of the national STEM education initiative. Yet, this influence does not entail *supporting* the rationale for the STEM agenda, rather it should *expand* the rationale. Tech Schools can potentially address many of the challenges of STEM education regarding general employment capabilities; student participation and performance; and fostering innovation by presenting a more holistic model of education which draws from STEM subjects as well as the humanities and the arts. The paradigm shift from STEM to STEAM requires a fundamental reorientation of motives, and means for education. For this reason, Part 3 of this section will explore the STEAM movement in education.

Part 3: Does STEAM Address STEM Issues?

The Victorian Government has promoted Tech Schools as STEM education centres. A number of Tech Schools have modified this vison to incorporate the arts and the humanities through the development of STEAM programs. A total shift from STEM to STEAM is proposed in this thesis to avoid reinforcing the current dichotomy between the sciences and the arts or more broadly STEM and HASS (humanities, arts and social sciences). Tech Schools could provide a more democratic approach to student preparedness for employment through inclusivity and diversity of engagement, rather than the existing “STEM pipeline” construct promoted in national reports. The following section of the review is dedicated to clarifying the meaning of the “A” in STEAM as it is not a well-defined educational concept (Colucci-Gray, Burnard, Gray, & Cooke, 2019).

The use of acronyms in education such as STEM and STEAM can be a distraction from the fundamental principle that *authentic learning is experienced whole*, not as a set of disciplines (Dewey, 1938/1997). Yet, clarifying the difference between STEM and STEAM is not trivial as it underpins political, financial and curricula commitments to education. It addresses a long-standing epistemological debate regarding the relationship between science and art in education (J. Bruner, 1986; Snow, 1964). Through data driven policy and quantitative assessments, education and society seem to be shifting towards increased technocracy (Feenberg, 1991; Greene, 1978). Within Australian education, a focus on developing scientific and digital literacy has been promoted, at the expense of the arts and the humanities.

The announcement in June 2020 by the Hon. Dan Tehan, Minister for Education, that Australian universities will decrease the cost of some STEM subjects while doubling the cost of some humanities courses is an example of this political bias in education (Karp, 2020, 19 June). Yet, support for STEM over HASS is not unanimous in Australian politics. For example, the former New South Wales Education Minister, The Hon. Robert Stokes denounced the “STEM craze” in education, which he attributed to a “propensity for disciples of STEM to apply the ontological reductionism of the scientific method to education more broadly” (2018). Thus, there is a need for diverse perspectives on how to increase student engagement in school mathematics and science, while also considering the need for science to be culturally embedded in history and narrative, to promote *intellectual democracy* in education (J. S Bruner, 1996; Dewey, 1916/2010).

The incorporation of the arts into Tech School programs is intended to encourage creativity and the representation of ideas, through a *design-thinking process*. STEAM programs support the development of *Capabilities* from the Victorian Curriculum and the Australian Curriculum, which Taylor (2016) considers important for meeting the opportunities and challenges of the twenty-first century. Creative and critical thinking, ethical, intercultural, personal and social capabilities from the Victorian Curriculum are fostered through STEAM as well as providing a cultural platform for exploring the *Cross-curriculum Priorities* (VCAA, 2018). These include:

learning about Aboriginal and Torres Strait Islander histories and cultures; Australia's engagement with Asia; and sustainability. Through the arts and humanities, cultural perspectives can provide rich content connections as well as promoting alternate world views by relating cultural and social issues to scientific solutions for empathetic problem-solving (Boy, 2013; Guyotte, Sochacka, Costantino, Walther, & Kellam, 2014). While the development of a Tech school STEAM program represents a milestone for interdisciplinary education, further clarification of the "A" is still needed.

The "A" in STEAM is a marker for the role of art, although "art" in this context does not define a single discipline. Rather, art in STEAM encompasses alternative epistemologies with an emphasis on qualitative rather than quantitative ways of knowing (Colucci-Gray et al., 2019). This review of literature posits that the A in STEAM represents three domains of study relevant to education: *the creative arts; the humanities; and the liberal arts*. The first two are directly relevant to Tech Schools, while the third – the liberal arts, broadens STEAM from problem solving projects to inquiry projects for personal development. The term "liberal arts" is not commonly used in Australia, but widely used in the US and internationally as an umbrella term for the arts, the humanities and the general capabilities. The three proposed meanings of the A in STEAM are:

1. *The arts* from the curriculum, which includes the diverse disciplines of visual arts, dance, drama and media as well as visual communication and design. This interpretation of the A as the arts, focusses on the promotion of creativity, representation, design and interpretation. The A is aesthetically focussed as a product and as a process (Eisner, 2003).
2. *The humanities* from the curriculum, which promotes the consideration of world issues such as history, geography, civics and citizenship, economics and business. The A as the humanities, is culturally and morally focussed (Dewey, 1959).
3. The A in STEAM can also represent the *liberal arts* for developing general capabilities from the curriculum. Liberal arts driven STEAM promotes learning for the development of personal and social capabilities; ethical and intercultural understandings; creative and critical thinking needed to engage in society as imaginative, socially aware and ethical humans (Deresiewicz, 2014). This third meaning of the A is not distinct from the arts or the humanities in STEAM, yet it

frames STEAM education within a humanist paradigm of learning for personal, social and cultural development.

For an in-depth description of the first two meanings of the A in STEAM (the creative arts and the humanities) refer to the article included in Appendix G. (Sacrez, 2020). This article – submitted for publication – also outlines how STEAM programs in Tech Schools can be linked to the Australian Curriculum to support secondary school interdisciplinary units. While Tech School programs provide a valuable model of STEAM based on the design thinking process, the focus on *solving problems* may overlook the importance of learning for the sake of *personal development and self-actualisation*. For this reason, only a brief description of the arts and the humanities in STEAM is included while the value of STEAM from a liberal arts perspective is emphasised.

Tech School problem-based STEAM projects can be seen as meeting the requirements of the Third Industrial Revolution (3IR) with an emphasis on *user-centred* solutions-design using industrial technologies. Yet, a liberal arts approach to STEAM could represent a necessary emphasis on fostering a *humanity-centred* ontology to balance the increased impact of AI and automation in society. Countries such as Korea are making the shift towards a liberal arts approach to STEAM to promote the necessary soft skills and capabilities for the 4IR (Chu, Martin, & Park, 2019; Y. Lee, Moon, & Kwon, 2019).

The arts in STEAM.

The arts have a distinct role in developing humans' subjective understandings of the world, by promoting the act of perception. Philosopher John Dewey (1959), noted in his book *Art as Experience*, that this is the difference between *recognition* – our usual mode of categorising and labelling – and *perception* as an aesthetic experience. It requires a slowing-down of our intake of sensory data to savour the qualities of what we are experiencing and placing emphasis on observation before action. This is relevant to Tech Schools which *may conflate art and design*. While both design and art are creative, design is primarily a presentation of an idea with a function, while art is a re-presentation of human experience of the world (Eisner, 2002). Allowing time for exploring and communicating creative art experiences is important before these insights are applied to solving a practical problem through design.

Art is a reminder for Tech Schools to not substitute science and technology for culture and nature when seeking to innovate. As science increasingly exploits the vast potential of technology for inspiration, the even vaster potential of *nature for insight* should not be overlooked. This necessitates that, institutions for science and for art provide access to natural artefacts, and experiences in nature (Louv, 2012; Maeda, 2017). Further, as science proceeds to utilise digital technology for simulating, experimenting, conceptualising, manipulating and presenting visual *immaterial objects*, art provides a sophisticated language to question what is real and what is imagined (Knochel, 2018).

In summary, the arts in STEAM bring new perspectives to the notion of design in manufacturing as well as extending *beyond design* which is relevant to Tech School programming. Tech School STEAM programs provide strong links to *half of the arts* in the Victorian curriculum through media arts, and visual communication and design. Yet, Tech School programs may be missing connections to the other half of the arts which includes the embodied and experiential arts of drama, dance, music and visual arts which do not naturally fit the industry-solutions model of Tech School programs. To authentically promote STEAM to arts teachers in schools, Tech Schools will need to think beyond design and provide opportunities for creative exploration of the natural world through open inquiry.

The humanities in STEAM.

The humanities provide a cultural and historical account of societal progress, to promote discussions about *ethics* and *empathy*. This creates an authentic learning context to integrate the curriculum capabilities – ethics, critical and creative thinking, personal and social and intercultural capabilities – into STEM subjects. Through the use of technology, engineers and scientists are able to make significant medical, environmental and social progress, yet the long-term effects are not always well-considered (Lachman, 2018). While the primary focus for STEM and Tech Schools is to build industry partnerships and increase participation in STEM careers, there seems to be lack of emphasis on critical thinking regarding the *social impacts of progress*. Lachman (2018) highlights three examples of the need for the humanities for ethical STEM development.

First, the increasing use of big data to perpetuate social inequality through biased mathematical modelling where “many poisonous assumptions are camouflaged by math and go largely untested and unquestioned" (O'Neil, 2016). Second, risky climate engineering mechanisms (CEM) are being proposed to cool the planet, such as seeding Cirrus clouds with mineral dust particles (Storelvmo, Boos, & Herger, 2014). Third, the unregulated progress in human germline engineering could result in unforeseeable negative consequences for the embryo and human development over a lifetime (Lanphier, Urnov, Haecker, Werner, & Smolenski, 2015). A recent example of this, is scientist He Jiankui's use of the CRISPR genetic editing technique for the genetic modification of human embryos without approval from the international scientific community (Klein & Le Page, 2018).

These examples demonstrate that technology is proceeding at an accelerated rate, which will require *critical thinking by students beyond STEM skills*. It requires school students, teachers, academics and industry to engage in reflective discussions about technology and to ask: "What moral purpose *should* a new technology serve?" For this reason, Tech Schools could play a pivotal role in presenting perspectives from the humanities and involving diverse stakeholders beyond STEM fields in the design of programs and events.

Liberal arts STEAM.

The liberal arts represent learning for human development in any discipline, in which the predominant object of the activity of learning is *not* professional career skills development, but personal and social development. This is a contested view of education, particularly in the context of Tech Schools' industry focus. Yet, learning through *engagement with industry* does not have to entail learning to develop *skills for industry*.

As William Deresiewicz notes in his book *Excellent Sheep* "Before and beneath the public good a liberal education serves a private purpose, for building a self" (2014, p. 83). He believes that this is lacking in the current neo-liberal education model, where learning can be packaged and sold as a commodity. While terms such as "critical thinking" are marketed as key employment skills in a neo-liberal context of education, the liberal arts promote a *critical consciousness* of the influence of history and ideology on social systems, which Freire referred to as "conscientization" (1996, p. 127). Tech Schools could build from this critical awareness of social issues to foster *critical social action* – activism – by students to address issues in their schools and local community. In this capacity, Tech Schools would represent a positive disruption to the education system in promoting a move from curriculum-determined forms of *critical thinking* to student-determined forms of *critical action*. It would entail a rejection by schools – including Tech Schools – of packaged educational programs (commodities) aimed at promoting specific political agendas, in favour of using Tech Schools as a means to enact change (service). Whether Tech Schools have the radical capacity for providing *educational service rather than educational commodities* is fundamental to their own conscious development of an institutional identity. It marks the difference between Tech Schools promoting a liberal versus a neo-liberal model of STEAM education.

Liberal arts STEAM should also be relevant to the Tech School initiative because the STEM movement in education is focussed on career readiness as an educational priority, yet, as careers are constantly changing, a *creative innovative mindset* is promoted as the fundamental career skill for the twenty-first century (Cunningham, 2018, March 22; Taylor, 2016). This reflects a tension, as career-readiness and creativity are not always compatible aims for teaching and learning. For example, an over-emphasis on vocational learning can result in over-specialisation which reduces diversity of innovation within, and across, professions (D. Edwards, 2010), while also reducing the level of excellence for high achieving students (van der Wende, 2011). This would contradict the central aims of the STEM initiative: to increase *excellence* and *innovation*.

Career-readiness is not necessarily what has driven great advancements in STEM fields. The type of discoveries which present the world in a new way, which Thomas Kuhn called "Revolutions" or "paradigm changes" in his book *The Structure of Scientific Revolutions* (Kuhn, 1962/2012, p. 115). Driverless cars, space travel, AI and nanotechnology are certainly growing industries for the future and should be studied as part of science and technology. Yet, they also have been written on the pages of science fiction comics and books made for enjoyment by adults and children, who have gone on to make science fiction into science, without recourse to political or professional ambitions. The A in STEAM, permits the question: "What if?", to enable imagination to wander freely amongst diverse fields of knowledge. This is promoted through the liberal arts, where discovery is driven by a creative thirst for knowledge and truth in all disciplines including – but not limited to – science, technology, engineering and mathematics.

In adopting a STEAM model of program design, Tech Schools may need to consider the value of *inquiry models of project-based learning*, which focus more on the development of personal interests than collective skills. As will be demonstrated in later sections of the review, the design thinking process used in Tech Schools has a broad enough scope to accommodate the development of *collective, social* and *personal* capabilities through STEAM.

Summary of Part 3: STEAM.

Based on the literature presented, for the Tech school initiative to have impacts on improving student participation and performance in STEM subjects (without reductionism or exclusivism), will require the integration of the “A” in its many forms. Potentially, the value of the A in STEAM is in highlighting alternatives in societal progress allowing for flexibility and adaptability to change. Further, the disciplines represented by the A could provide qualitative tools to analyse the ambiguity of human reality, which can lead to innovation and foresight. Having established a general rationale for STEAM, examining how Tech Schools develop STEAM programs and support schools to develop their own STEAM programs is the central aim of the research study. The design of Tech School STEAM programs is examined in-depth in Section 2, Part 2 of this literature review.

Summary of Section 1: Education for the 4IR

The Tech School initiative has been contextualised from a sociological perspective as a means of preparing students for the 4IR. In Part 1, The current emphasis on a standardised, globally competitive education system was shown to be reductive in overlooking the dialectical relationship between industry, society and education. By undervaluing the social structures which underpin innovations in industry, Australian education has reduced pedagogy to curriculum delivery, while conflating innovation and technology. It was argued that developing more adaptable, collaborative and community-orientated school practices through interdisciplinary projects – such as Tech School projects – would better prepare students for the 4IR. Whether Tech Schools can capitalise on their political position to lead these educational restructures as “mediating organisations”, and whether this fits with their own strategic vision are questions explored throughout the rest of the thesis.

In Part 2, the rationale and aims of the Tech school initiative were examined within broader national goals for STEM education. Assumptions regarding the importance of STEM for fostering innovation; improving student participation and performance in school science and mathematics; and developing capabilities for industry were examined and found to be ideologically rather than educationally founded. Tech Schools have the potential to reframe STEM education aims to promote a progressive transformation of education, where student and educator experiences qualitatively inform policy changes in future.

Part 3 outlined one way that Tech Schools are transforming the deterministic STEM pipeline model to a STEAM model of education. Literature was provided on the benefits of incorporating the arts, the humanities and the liberal arts to create diverse opportunities for: student engagement and activism; teacher collaboration between disciplines; and authentic connections across the curriculum including the Capabilities. Finally, it was recommended that the Tech School model of STEAM, based on solving community and industry problems could be expanded through a liberal arts inquiry approach to STEAM. This would reflect a shift in education from vocational skills needed for the 3IR; to personal, social and collective capabilities needed for the 4IR.

This critical evaluation of STEM education relative to political, industrial and societal developments contextualises the Tech School initiative. Section 2 will focus specifically on Tech Schools as mediating organisations for supporting secondary schools to embed STEAM programs and more broadly, to reorientate Australian education towards a more authentic model of pedagogy and program design.

Section 2. Tech Schools: Potential Impacts on Education

Section 1 of the literature review considered the Tech School initiative as part of a systematic intervention to improve participation and performance in STEM subjects informed by political and economic goals. This political perspective is at odds with education from a cultural perspective, where the purpose for learning is contextualised in praxis (Bruner, 1996; Cole, 1996; Eisner, 2002; Thompson, 2015). Tech Schools have a mediating role in translating the economic and political goals of STEM into an educational context for students, teachers and schools to engage with industry and community through projects. This context, consisting of *personal, social and collective* platforms for engagement resulting in different impacts on education, is the focus of this section.

Section 2 examines the potential impacts of Tech Schools on education. Four impacts are highlighted with reference to literature on global developments in education. These are (1) in-house programs which engage students through experience with new technologies and learning environments; (2) Developing STEAM programs and trialling innovative pedagogies; (3) professional learning for teachers; and (4) fostering collaborations between school, industry and the community. Each of these impacts is examined in terms of the enabling and constraining factors on students and teachers involved in the Tech School initiative. The role of a Tech School in mediating between stakeholders – as a "mediating organisation" – is the overarching theme that relates the four parts of this section.

The Educational Context of Tech Schools

Tech Schools are part of a cultural shift in education towards authentic tasks, formative assessments, transdisciplinary curriculum, and the collaborative construction of knowledge (Lucas et al., 2013; Luna Scott & UNESCO, 2015; Wagner & Dintersmith, 2015). Emphasising that developing *learner capabilities* is equally import to learning *discipline-specific content* is a growing trend in education, with twenty-first century skills becoming central to contemporary curriculum design. (Kai Wah Chu, Reynolds, Tavares, Notari, & Lee, 2017; Soland, Hamilton, & Stecher, 2013; Trilling & Fadel, 2009). This shift does create tensions in STEM programs, as a lack of emphasis on mastering content may result in graduates lacking fundamental mathematics and science knowledge (Education Services Australia, 2018). This tension between general capabilities and specific knowledge is integral to the "culture of education" with emphasis fluctuating in response to shifting historical and societal requirements (J. S Bruner, 1996).

Industry is once more changing, in response to the social potential of technology, placing greater emphasis on developing learner capabilities such as creativity, critical thinking, communication and collaboration (Ministerial Council on Education, 2008). A narrow and standardised curriculum is now proving inadequate for preparing Australian students for modern employment, where transferrable enterprise skills are increasingly needed (Foundation for Young Australians, 2017). The great challenge for Tech Schools and more broadly for the STEM initiative, is to create learning programs that overcome the antinomies of excellent content knowledge (which is testable and measurable), and innovative thinking (which currently is not). Tech Schools could mediate this dialectical tension, by providing a qualitatively new context for promoting and evaluating student development. This is central to discussions regarding education *as a system and as a culture*, by highlighting what type of learning is valued, why it is promoted, and how it is to be evaluated (The Partnership for 21st Century Skills, 2009)

There seems to be a crisis in STEM education regarding a perceived need for increasingly specialised knowledge in the fields of science and technology, yet teaching in a specialised manner through distinct subjects is not engaging for many students (Osborne, 2007). This is one of a number of antinomies in Australia's current system of education mediated by Tech Schools. This is discussed in detail in a publication by the author in Appendix H (Sacrez, 2020). Through the development of authentic projects, Tech Schools are a means for mediating between: theoretical and practical knowledge; teacher-centred and student-centred learning; disciplinary and interdisciplinary approaches to program design. It is proposed that these antinomies emerged through a neo-liberal model of education whereby gaining an education was an efficient pathway to specialised professions (Desjardins, 2015; D. Smith, 2011). The project-based approach to pedagogy and program design utilised in Tech Schools could provide a more suitable model of education for an increasingly complex and interdisciplinary future of work. It is one of many models of progressive education reframing the paradigm of educational achievement through project-based, problem-based and design-based learning (Fullan, Quinn, & McEachen, 2018).

Potential Impacts of Tech Schools on Education

Tech Schools are described in this thesis as "mediating organisations" to better relate schooling to the evolving needs of industry in the 4IR. It reflects an ideological change in Australian education towards applied learning through projects which connect to local industry and community organisations. Yet, as Serdyukov (2017) notes, schools are not fond of revolutionary changes, as existing paradigms reflect an internal logic between established rules, tools, practices and beliefs. They represent a reliable system of production which cannot easily adapt to significant change. Yet, the end product of traditional education is no longer adequate in meeting the needs of industry and society (Zhao, 2012b). Tech Schools' political attempt to innovate the system of education to become more adaptable to diverse and evolving needs of industry requires cultural change.

Tech Schools serve this politico-cultural role by reframing school ideology and practice (praxis). This intervention has required a multi-level and multi-layered strategy for shifting institutional practices in schools to impact on key aspects of education. Four potential impacts of Tech Schools on education are considered and related to international changes to education:

1. Constructing innovative learning environments for engaging students
2. Experimenting with STEAM program designs and new pedagogies
3. Providing professional development/learning for teachers
4. Fostering collaborations between school, community and industry

Each of these potential impacts will be elaborated separately with examples from education literature.

Part 1. Innovative Learning Environments for Engaging Students.

(i) Physical space.

Tech Schools do not operate under the existing structures of secondary schools, which reinforce the status quo by segmenting space and time through classes and timetables, which limit student agency (Fullan, Hill, & Crévola, 2006). Woodman (2016) relates this compartmentalisation to Foucault's theory of power structures, which are common to hospitals and prisons. Tech Schools, in providing a fluidity of space and time, promote boundary-crossing as an essential aspect of innovation.

Tech Schools as innovative learning environments (ILEs) are designed on principles of *reflexive* organisation of space. According to Cleveland, this adaptability of space can provide students with "geographic freedom" to engage with the environment, which is enhanced when the traditional construct of directionality becomes unbounded, promoting student construction of learning rather than teacher delivery from "the front" (2016, p. 43). Reflexive, as opposed to fixed usage of space, can promote a similarly "un-designed" approach to pedagogy if teachers are willing to engage with the cultural affordances of the space (Alterator, 2018, p. 148). From this perspective, innovative teaching practices involve *dynamically coordinating the social affordances of practice and physical affordances of space* to promote engaging learning experiences for students.

Despite flexibility being a premium quality of a Tech school space, in catering to a variety of programs, *partly-fixed layout* design can help to differentiate between spaces and help to structure intended interactions between students. Rather than providing completely open spaces which lack distinctions between small group, individual and communal space, Fisher and Dovey suggest the application of a "typology of learning spaces" which facilitate diverse student-centred pedagogies (2016, p. 165). Terms such as "Streetspace", "Commons", "Meeting area" and "assemblage" allow for a vocabulary that assists in the sophisticated usage of space-affordances based on pedagogical intent (Kenn Fisher & Dovey, 2016, p. 165). Tech Schools may support educators and students by using established terminology such as "makerspace", or through the development of their own spatial terms such as "discovery room".

Physical space as an affordance of Tech Schools has been reviewed, with an emphasis on the relationship between activity, pedagogy and design. ILEs are an evolving field of research in education, requiring ongoing study of the type of skills needed to capitalise on space affordance (Alterator & Deed, 2018). Establishing the pedagogical impact of ILEs may be facilitated by asking the following two questions:

1. Is this an innovative "*learning-environment"*? (The environment is innovative).
2. Is this an "*innovate-learning*" environment? (The learning is innovative).

Tech Schools which answer "yes" to the first question, but "no" to the second, may not be utilising the learning features of the environment effectively to meet the Tech School aim of fostering *innovative thinking and action* in students and educators. Tech Schools provide opportunities for substantial and ongoing research on the influence of ILEs, yet distinguishing between the impact of space, tools and curriculum on pedagogy is complex, in addition to understanding the educator beliefs regarding changing their pedagogies in ILEs.

Implications for educators.

As many students and teachers will be new to the Tech school environment, a need for contextual cues should be considered in encouraging particular types of interaction with the environment to avoid confusion (Woodman, 2016). While the Tech school layout, furniture and tools may have inherent technical affordances, it is the *activation of these affordances* through social and physical interaction which promotes intended behaviours such as team work, innovation and curiosity. As teachers develop expertise through experimentation and training in the effective use of space, part of their pedagogical practice will involve using the environment as the "Third Teacher" (Bertram, 2016, p. 105).

Ultimately, the learning environment is a stage which allows for actors to interact in non-traditional ways (P. A. Gross, 1997). As a stage, the environment does not directly impact on learning and teaching. Rather, it creates "cultural affordances" for particular social and professional relationships between teachers and students such as team teaching and different types of group work (Alterator, 2018, p. 145). Innovative teaching and learning are still dependent on the motivation and capacity of educators and students to actively engage (Imms, 2016). Educators' resistance or openness to change is the deciding factor in determining whether teaching is innovative, regardless of the environmental potential for innovation in a Tech School or a classroom.

(ii) Tools and technologies.

The concept of tools may bring to mind such things as low and high technologies. These are examples of physical and digital tools. From a broader perspective, mediating tools can also include social and conceptual tools (L. Vygotsky, 1978). This is relevant to Tech Schools as emphasis may be placed on innovative *physical tools*, without adequate consideration of the educational importance of *social tools* used by educators for effective communication, *conceptual tools* such as heuristics for problem solving, as well as the curriculum as an *instructional tool* for mediating the development of skills and understanding (Jerome S. Bruner, 1977). Artefacts or tools, which Wartofsky regards as "objectifications of human needs and intentions" in all forms can be used to enable a change in culture – including the culture of education (Mariane Hedegaard, 2007, p. 255). Wartofsky's concept of "primary artefacts" such as tools for direct production, "secondary artefacts" as representations of actions, and "tertiary artefacts" described as abstract representations in the mind, expand the potential for developing a culture of innovation in Tech Schools (1979, pp. 200-201).

The unique equipment on offer in a Tech School can provide deep connections between scientific concepts, discussion, materials and tools which Hetherington and Wegerif (2018) term a "material-dialogic approach to pedagogy". This capacity to relate diverse resources including the *physical*, *social* and *instructional* affordances of a given situation, is central to the construction of new knowledge in context, resulting in innovation. Of further importance, is connecting resource affordances to a conceptual framework (either physical or mental) to *transfer learning beyond the particular context*, thereby overcoming limitations of situated learning (A. Edwards, 2005). Dewey notes the importance of transferability of learning for students as citizens, to apply scientific conceptions to their daily lives (Pieratt, 2010). Transferability of knowledge is also needed for educators to connect theoretical concepts into practice across different contexts (Korthagen, 2017; Shulman, 2013).

Constructionism in Tech Schools: Pedagogical considerations for makerspaces.

Unlike the shift in education towards digitalisation of learning, where learning can occur anytime and anywhere, Tech Schools embody the theory of situated learning (Lave & Wenger, 1991). Knowledge is constructed in a situated context as students interact with the environment; materials and tools; and with each other (Cobern, 1993). Tech Schools as "makerspaces" are designed to create situations where students *experience* learning (Dewey, 1938/1997). For learning to be an "embodied" experience (Johnson, 2007, p. 13), thinking should occur *in* action, which raises questions about shifts towards online programs and digital technologies in education. Finally, learning through *construction* necessitates that students physically interact with tools and media, whether high-tech or low-tech in a creative context (Papert, 1993).

Seymour Papert's theory of constructionism stems from the common epistemological stance as constructivism in stating that meaningful knowledge is constructed by the learner, not transmitted through instruction. Yet, emphasis is placed in constructionism on the relationship between the activity of creating a "public entity" by manipulating objects and tools and the mental activity of "building knowledge structures" (Harel & Papert, 1991, p. 1). From a cultural-historical perspective, it is through the activity of *internalising signs* and *externalising meanings* that humans develop a psychological relationship to their culture (Miettinen, 2001; L. Vygotsky, 1978). Further, construction as an activity can support the development of higher thinking, when it becomes a social practice involving discussion, collaboration and reflection (Leont'ev, 1978).

This cultural-historical perspective of constructionism is important in evaluating the educational potential of Tech Schools for two reasons. First, while Tech school makerspaces may promote construction with new tools such as 3D printing, robotics and Arduinos (Horvath, Cameron, Adrianson, & Adrianson, 2015), unless the *learning process* is altered, Tech Schools will not achieve more than a "first impact" on education

(Harel & Papert, 1991, p. 10). While Technology can provide a new method of delivering content, it is not an educational innovation unless it is used to promote new approaches to teaching or learning. The Interactive White Board (IWB) is an example of technology having the potential to either disrupt traditional pedagogies or to reinforce them (Byers and Imms, 2016). Whether an IWB is any different from a blackboard when used to group students around a lecturing instructor is questionable. Tech Schools need to provide opportunities for educators and students to *experiment with technology* to maximise learning using the full physical, social, and conceptual affordances of the Tech School context.

Second, constructivism from a socio-cultural perspective involves a dialectical interaction between processes which occur within the mind of the learner and the world (Liu & Matthews, 2005). According to L. Vygotsky (1978) meaning making occurs on both the interpersonal and the intrapersonal planes of consciousness, through social-cultural interactions with others which are then internalised. In a Tech School, two activities are occurring simultaneously: the *externally visible activity* of construction through social collaboration, and the *internal development of conceptual relationships* between symbols and representations. While in theory, student engagement in the first (external) activity should lead to the development of the second (internal) activity, how can this be evaluated? Determining the difference between learning and playing in a Tech school, necessitates sophisticated means of assessing development, particularly if the program is to serve as an alternative to the current standardised test-driven model of education. Tech Schools need to develop rigorous methods of evaluating student development of capabilities and skills, beyond the assumption that physical construction represents conceptual construction.

In summary, Tech Schools have an important role in ensuring that technology does not serve as a proxy for situated learning between people, through an emphasis on construction in purpose-built makerspaces (Harel & Papert, 1991). How technology supports meaningful learning in Tech Schools requires an evaluation of technology affordances from the perspective of educational theory (L. Harasim, 2012; Stenild & Iversen, 2012). The pedagogical implications of Tech Schools as unique socio-technological environments will now be discussed as well as the significant role of the curriculum and program structure of Tech Schools as *secondary artefacts* for cultural change.

Part 2. STEAM Program Designs and Constructivist Pedagogies.

(i) Tech School STEAM programs.

The design of STEAM programs is one of the most innovative aspects of Tech Schools as it is a reversal of traditional school programming. Whereas school programs are *built from the curriculum*, Tech School programs are *built from community and industry issues* which fit within the DET industry foci. Seven industry sectors have been highlighted by the Victorian Government as areas with high economic and employment growth: “medical technology and pharmaceuticals, new energy technologies, transport, defence and construction technologies, food and fibre, international education and professional services” (State of Victoria Department of Education and Training, 2016, p. 3). Tech Schools co-design programs with industry and community representatives from these growth sectors to identify key issues needing solutions. These issues serve as authentic challenges for students to engage with specific content, knowledge and skills, as part of the process of solving problems. In this way, Tech School programs are a mix of problem-based learning (Huijser, Terwijn, & Kek, 2015) and project-based learning (Kanter, 2010). The *problem-centred project-based learning* model used by Tech Schools also has similarities to Zhao’s “entrepreneurial PL Model” in its focus on the design of a product or solution (2012b). Specifically, Tech Schools use a design thinking process based on the Stanford “human-centred design” model which structures the program into stages to support students to design solutions (Plattner & Institute of Design at Stanford, p. 1).

Once a 3-day Tech School program is developed, curriculum links from different subjects are embedded into each stage of the design thinking process for the program. Teachers have the option of integrating the program into their school as a standalone STEM subject, an elective program or as an interdisciplinary unit of work. It is here argued that the impact that a Tech School program has on student learning, is dependent on *how deeply it is integrated* in a school, *how well it connects to the curriculum* for assessment and reporting and *how much direct engagement* the school has with local industries and the community. Tech Schools can support each aspect of program integration and school-industry connection. Within this section of the literature review, first, the 3-day Tech School programs will be evaluated as a standalone *transdisciplinary* model, then the potential advantages and challenges of integrating the program as an *interdisciplinary* unit will be considered. Fostering school connections to industry and community will be examined separately as the fourth potential impact of Tech Schools.

Transdisciplinary project-based learning.

The most common approach to STEAM programming in schools is through a *transdisciplinary* design by flexibly utilising content from the mandated curriculum as it suits the requirements of the project or student interest (Bequette & Bequette, 2012; Guyotte et al., 2014; Liao, 2016). According to Lattuca, transdisciplinary teaching is "the application of theories, concepts, or methods across disciplines with the intent of developing an overarching synthesis" (2001, p. 83). As an inquiry process in education, this can be either an opportunity for deep learning through the exploration of connections, or it can be a confusing and potentially frustrating experience for teachers and students without set content and aims to ground inquiry (MacDonald, Hunter, Wise, & Fraser, 2019; Thomas & Huffman, 2020b). Further, according to the Victorian Curriculum and Assessment Authority (2015) there is the possibility of missing fundamental disciplinary concepts from a breadth-over-depth approach to teaching. This is an ongoing challenge for STEM and STEAM curriculum design, and a serious topic for discussion and research (Education Services Australia, 2018; Ge, Ifenthaler, & Spector, 2015; Cassie Quigley, Harrington, & Herro, 2017 ; Shulman, 2013). Using processes such as design thinking for solving a problem (Plattner & Institute of Design at Stanford) or the 5E model for inquiry (Bybee, 2015) can help teachers to structure the program, allowing for evaluation of student projects and their learning at key milestones.

When developing a STEAM program, Watson advises "the point is not to try and cram every discipline into every project, but rather to regularly and authentically make connections between the disciplines whenever it makes sense to cross borders" (2016, p. 8). Rather than leaving this process to chance, Tech Schools establish project parameters to ensure that learning is centred on developing skills in science and technology, by relating content from the Victorian Curriculum to industry foci. In this way, Tech School programming utilises a *transdisciplinary* approach to *teaching*, structured through an *interdisciplinary program* and enacted through *project-based learning*.

While interdisciplinary and project based-learning are part of a long tradition of progressive education (Kilpatrick, 1918/2020), Tech Schools are innovative in designing programs that place greater emphasis on the application of skills, rather than on the acquisition of knowledge (Sacrez, 2020). This raises a challenge for teachers, as skills cannot be applied in the absence of knowledge which is discipline specific (Jerome S. Bruner, 1977; Herro & Quigley, 2017; C. Quigley, Herro, & Jamil, 2017). Developing a dynamic relationship between the *means and the outcome* of learning in Tech Schools, will require learning that is reflexive, negotiable and non-linear. Establishing a culture of collaboration between discipline experts, and educators in a Tech school could support interdisciplinary learning while maintaining integrity of discipline knowledge (Herro & Quigley, 2017). This model is applicable both to teams of teachers and teams of students, in developing projects in their base schools.

A difficulty in developing a STEAM program is the time invested without clearly being able to assess learning growth against curriculum standards (MacDonald et al., 2019). This can be an obstacle to program development, especially if all teachers are not on-board (Hunter-Doniger & Sydow, 2016). Teachers may value STEAM as a holistic process of learning, yet have concerns about meeting curriculum content standards, as well as overcoming certain logistic problems with timetabling, assessment, reporting and supporting multiple student projects with different needs.

The development of projects which extend beyond the classroom can be facilitated, by partnering schools with industry experts in organisations which are STEM or STEAM-based, (Australian Industry Group, 2017; Education Services Australia, 2018). Museums, zoos, libraries, nature centres, aquariums and art galleries are institutions which model collaborative STEAM in preparing their own exhibits and informal learning environments (Grant & Patterson, 2016). Further, they will often have educational programs that can be utilised by teachers in establishing a school project or a personal collaboration between students and staff (Quigley et al. 2017). Ultimately, Tech Schools are just one of many public organisations with rich STEAM-learning potential.

As models of best practice emerge from research into Tech school learning and teaching, it can be predicted that an increase in professional development courses will become available to teachers (Aslam, Adefila, & Bagiya, 2018). These could include workshops on interdisciplinary and collaborative curriculum design, as well as teacher partnerships with industry and community members (Flores, 2017). This will require not only an upskilling of STEM skills, with technology being a dominant focus, but also an open dialogue between teachers and policy makers to ensure that professional learning emerges from practice not just theory (Darling-Hammond, 2017; Korthagen, 2017)

Tech School project based-learning using a human-centred design process.

Tech School programs use a design thinking process to scaffold student projects. While a design process is common to STEM fields such as engineering, *human-centred design* adds a social dimension to understanding and solving a user's problem (IDEO, 2011; Plattner & Institute of Design at Stanford). By starting the design thinking process with *empathy for the user* and a *definition of their needs*, the techniques, tools and technologies used to create a prototype are orientated towards addressing the root cause of the user's or the community's problems. This avoids superficial solutions which either misunderstand the needs of the user, or in some cases aggravate the problem by creating new needs (Meinel & Koppen, 2015).

Based on the Stanford d.school five-stage model of design thinking (Plattner & Institute of Design at Stanford), Tech school projects direct students through seven stages of an iterative design cycle:

1. Empathise: Collecting information about the user and the problem to be solved
2. Define: Creating a problem statement based on understandings of the user's needs
3. Ideate: Group brainstorming to collect a high volume of diverse and creative solutions
4. Prototype: Constructing a physical representation to help conceptualise the solution
5. Test: Sharing the prototype with the user to gain feedback for modification and redesign
6. Pitch: Students communicate their solution to the problem to an audience including community/industry leaders
7. Reflect: Team discussion about successes and failures to reinforce collective learning and promote a new iteration of the design thinking process

These seven processes structure Tech school programs into sequential stages. Yet, the *process is iterative* as reflecting on feedback from industry leaders can lead back to more refined research on the user and the issue to be solved. Further, smaller cycles within the process may be repeated such as creating multiple prototypes based on test results (Luka, 2014).

The Tech school design thinking process promotes a structured approach to project management in education, with clear milestones for evaluating learning, explicit opportunities for emphasising capabilities and making connections across disciplines. As a pedagogical tool, the design thinking process allows for the interrelation between the learning-activity of the students engaged in solving a problem, and the teaching-activity of educators who reflexively modulate the learning process by emphasising key skills, responding to student needs, embedding content, highlighting concepts, and providing instruction as needed (A. Diefenthaler et al., 2017).

The design thinking process can be used for integrating the Capabilities from the Victorian Curriculum (Victorian Curriculum and Assessment Authority, 2019). *Ethical and intercultural capabilitie*s are authentically utilised to empathise with the user to initiate the design cycle. *Creative and critical thinking* are utilised in exploring potential ideas, which are developed into solutions to problems. Throughout the process, *personal and social capabilities* are employed through collaboration on projects and the communication of findings. Rather than having the Capabilities taught as an independent topic out of context, or assumed to be a natural part of learning, the design thinking process allows educators to incorporate the Capabilities into defined stages to support student projects. This adds relevance for the Capabilities as learning processes, which can be explicitly highlighted, taught and assessed in an authentic context. An article by the author detailing how the design-thinking process can be used to integrate the curriculum into projects is included in Appendix G (see Sacrez, 2020a).

Regarding the role of the humanities for the development of a global consciousness, a potential pitfall of the design thinking process should be noted. As technology is amplifying the power, scope and speed of invention and intervention, a shift from *human-centred* to *humanity-centred* design is gaining support to avoid the production of short-term consumer-orientated products which cause long term environmental and social problems (Boy, 2013; Donelli, 2016; Girling & Palaveeva, 2017). Tech Schools engage students in an efficient process for meeting user and consumer needs, yet there is potentially a lack of critical thinking regarding the ethical basis for directing human activity towards satisfying *user needs* at the expense of the greater object of social equality and environmental sustainability (Lachman, 2018;

O'Neil, 2016; Winston & Edelbach, 2014). It would be irresponsible of Tech Schools to overvalue the commercial potential of innovation at the expense of fostering the development of globally conscious citizens capable of critical awareness of social and environmental issues.

In conclusion, Tech Schools have a rigorous model for project-based learning programs. It represents an innovative approach to integrating curriculum content, student interest and community/industry issues. There is now a need for Tech Schools to develop a pedagogically-orientated version of the process, with criteria for evaluating the quality of student learning. This is an area of research with potential benefits for the education system, through improved constructivist learning theory and an evidenced model of project-based learning, applicable to mainstream schooling.

Implications for teachers: Collaboratively designing interdisciplinary units.

Tech Schools present opportunities for teachers to experiment with new approaches to curriculum and pedagogy, outside of the regular routine and expectations of traditional schools. Collaboratively designed projects between students, teachers, industry representatives and tertiary educators allow for authentic learning with community impact (Aslam et al., 2018). Fostering relationships between these participant groups, supports the establishment of a network of expertise and resources, as part of Tech School "communities of practice" (E Wenger, 1999). Maintaining a clear vision of the educational purpose of Tech Schools is important to scaffold teachers' evolving praxis, which reflects broader discussions about the purpose of education in the twenty-first century.

Tech Schools will need to provide specific supports for teachers aiming to work in interdisciplinary teams, as they may lack knowledge and skills beyond their field of expertise (Berlin & White, 2012). This gap in knowledge may be mitigated by team teaching, yet school timetables are not necessarily suited to interdisciplinary classes, which require multiple teachers working in a single space. Aslam et al. highlight the need for "pedagogic space" to permit flexible times and policies for collaborative teacher planning and reflection (2018, p. 66). In summary, the development of a sustainable Tech School network could support teachers both formally and informally through resource sharing, STEM professional development programs and shared learning experiences (Bybee, 2013).

(ii) Evaluating project-based pedagogies in Tech Schools using constructivist theory

The cultural shift in education is driving new pedagogies where teachers: work in teams as facilitators, use formative assessment, structure learning through interdisciplinary projects and utilise the learning environment as a third teacher (Cingel Bodinet, 2016; K Fisher, 2005; Luna Scott & UNESCO, 2015; Serdyukov, 2017). Tech Schools operate within an alternative educational paradigm to mainstream schooling as the outcome of learning is different. Mainstream education has replicated a social system based on the notion of *division*. This paradigm employs a divide and conquer method. It *dissects*: the mind into different intelligences; activity into mental and physical; knowledge into subject silos; space into classrooms; leadership into hierarchies; and pedagogy into learning and teaching (Lucas et al., 2013; Wagner & Dintersmith, 2015). The notion of a *dissected schema* runs through all aspects of mainstream education.

Tech Schools represent a schema of *unification* by synthesising these educational antimonies. The *unified schema* of Tech School programs *relates*: thinking with action; academic with practical knowledge; school with community; work with play and learning with teaching. Further, these antimonies are *dialectically unified*, which means one cannot be studied separate to the other. For a comprehensive discussion of how Tech Schools mediate the unification of these antinomies refer to the entry in the Encyclopedia of Innovative Learning by Sacrez (2020b) included in Appendix G. Pedagogy as a dialectical relationship will be discussed in detail here as it allows for a revision of classic constructivist theories within the new context of Tech Schools.

Pedagogy as a dialectic between teaching and learning.

Two constructivist theorists at the turn of the twentieth century revealed the dialectical interrelation between learning and teaching. Despite working within different geographical locations and different political systems, *Vygotsky's socio-cultural theory* and Dewey's *constructivist theory* are similar in their focus on education as a multilayered construction between different participants. Dewey (1933) noted that to speak of teaching as a separate activity to learning is as nonsensical as speaking of selling without buying. Like buying and selling, teaching and learning are interrelated actions which cannot be analysed separately. They are *dialectically constituted* (Daniels, 2007).

The notion of pedagogy as a synthesis is inherent to both Vygotsky's original theories, and to the Russian language used to describe it. Take for example, the meaning of "Obuchenie", the Russian word for instruction:

> It means both teaching and learning, both sides of the two-way process, and is therefore well suited to a dialectical view of a phenomenon made up of mutually interpenetrating opposites. (Sutton, 1980, p. 169)

This dialectic of pedagogy is not apparent in mainstream schooling because the process of teaching, learning, assessment and reporting are designed as a *sequence of distinct activities*. Yet, the theory of pedagogy as a dialectic is well suited to the study of project-based learning which is *integrated and iterative*. An examination of the structural layers of this dialectic can ensure rigour in the design of projects and the evaluation of project-based pedagogies.

Personal, relational and collective layers of pedagogical activity.

Pedagogy has been described as dialectical. Yet, pedagogy is not an abstract concept. It is an activity involving a range of specific actions to achieve intended outcomes (Daniels, 2007). Within the context of project-based learning applicable to Tech School programs, pedagogy is multi-layered. Pedagogical actions and outcomes can be analysed within *layers of activity with corresponding psychological dimensions*. This is a common theme across constructivist learning theories which take a holistic view of pedagogy (Postholm, 2008).

In this review of the literature, pedagogy is examined as a tri-layered dialect. First, pedagogy has a *personal layer* in which the intended outcome is for a learner to experience agency and to develop personal capabilities. This requires differentiation of the program for meeting the learner's specific needs as well as making personal connections between the learner, the topic and the educator (L. Vygotsky, 1978). Within the context of the learning environment, pedagogy has a *relational layer* as participants interact as members of a learning community and engage in authentic practices during lessons. This requires the creation of an active learning environment and diverse forms of assessment of learning (Dewey, 1902/1971). Finally, at the core of a Tech School program is the project itself which students are undertaking as members of a team through the use of tools and skills to solve a problem. This *collective layer* of activity is similar to the division of labour in a workplace (Leont'ev, 1978). For this reason, the project should be designed to relate school learning to societal issues and activities.

These layers of pedagogy help to structure the activity of authentic project-based learning. They have a historic parallel in social psychology through the theories of American pragmatists George Herbert Mead and John Dewey who focussed on the relationship between the *development of a self-identity by participating in social roles*. In Russia, Lev Vygotsky developed a theory of social consciousness through the *internalisation of interactions with others*. Alexei Leont'ev broadened the focus of social psychology to study the multiple levels of activity in labour and learning. These two schools of psychology developed in parallel in America and Russia have remarkably similar notions of the dialectical and multi-layered process of human development which underpin constructivist theories of pedagogy. Brewer and Sedikides describe the social and cultural development of self-concepts in the introduction of their aptly named book *Individual Self, Relational Self, Collective Self*:

> This volume is based on the premise that the self-concept consists of three fundamental self-representations: the individual self, the relational self, and the collective self. Stated otherwise, persons seek to achieve self-definition and self-interpretation (i.e., identity) in three fundamental ways: (a) in terms of their unique traits, (b) in terms of dyadic relationships, and (c) in terms of group membership. (2001, p.1)

George Mead (1934) summarised the relationship between these types of self-identity as 'I' (personal-identity) and 'Me' (social-identity). To this, can be added 'We'(collective-identity). It is argued in this thesis that: *pedagogical actions aimed at supporting the complete social development of learners must address these three dimensions of self*. Further, studying pedagogy in layers allows for distinctions to be made regarding constructivist theories of learning as well the types of interactions which are promoted in a constructivist learning environment such as a Tech School. For this reason, key theories relevant to constructivist pedagogies are structured and summarised in these three layers. A table of key theories follows which was the basis for the development of an analytical framework for this study in Chapter 3.

(a) Program layer: Personal learning.

The individual learner can be seen as the starting point and the end point of a learning program. This is particularly relevant to Tech Schools as students visit the Tech School for three days, often without established relationships between the Tech School educators and the students.

Each individual student enters into the educational context with expectations, preconceptions and predictions of what they will be engaging in (Cole & Engeström, 1993). Regardless of experience, individual engagement and development in the activity is likely to be directed towards satisfying a *personal motive* (Leont'ev, 1978). From a humanistic perspective, an impactful learning program is strongly linked to a student's *self-esteem* by feeling empowered as an individual to take steps towards achieving their goals (Erikson, 1959). A program which promotes *intrinsically rewarding learning* can have a profound impact on the learner as it is an emotionally significant experience (Maslow, 1970). This subjective development of self-identity by the learner is fostered by pedagogies that allow for a high level of *student agency*.

Psychological constructivists such as Jean Piaget (1976), Ausubel (2000) and Novak (1993) emphasised the personal cognitive process of assimilating new information by reviewing and modifying students' *mental schema* on the topic. While a range of strategies can be valuable such as practice, rehearsal, concept mapping and thoughtful replication, these technical processes can become another bag of teaching-tricks which do little to build meaningful affective connections to the learning experience. Socio-cultural constructivists provide more adaptable, flexible and responsive pedagogical processes by building formal/scientific knowledge from students' *everyday lived experiences* (Daniels, 2007). Dewey, more than any other educational theorist, emphasised the importance of starting with the learner's beliefs, thoughts, ideas, projects, internal motivations and then expanding on them to deepen and broaden their perspectives (1902/1971).

The distinction between adopting a *cognitivist* or a *social* approach to building meaningful personal connections is not trivial. A social approach is not just a matter of assessing prior knowledge relevant to the topic, it is a matter of exploring the *sociological context* of the learner, which includes their participation in other institutions and social networks involving family and peers that shape their identity (Mariane Hedegaard, Edwards, & Fleer, 2012). Understanding the material conditions of the students' lives which are shaped by economic factors and cultural hegemonies related to class, extends the teacher's pedagogy from *social* considerations of learning to a critical *sociological* awareness of the learners (Giroux, 2001) and the application of "sociological imagination" to help learners' revise their social identity (Mills, 1959). To conceive of pedagogy in this way, is to reframe the existing paradigm of teaching from teachers as technicians to "teachers as cultural workers" (Freire, 1998).

Promoting the individual development of each student requires differentiating the program. Differentiation in education is often considered in terms of scaffolding a task to meet the student's zone of proximal development (L. Vygotsky, 1978). This is a valuable pedagogical strategy at the level of *task differentiation*, yet differentiating an entire program is not about matching the learner to a stage on a learning continuum. *Program differentiation* involves a common process to be undertaken by the students, but with multiple possible outcomes as students construct meanings based on personal interest, life experience and intrinsic motivations (Dewey, 1902/1971). Task differentiation has increasingly become systemised and technologized for tracking and streaming students along a learning progression between the student's current level and their future expected level (Department of Education and Training, 2018). In contrast, program differentiation is an expansive social process of allowing students autonomy to voluntarily shape the learning experience to meet their affective and intellectual growth as conscious agents (Engeström, 2016). The relationship between *reducing the task* relative to a standard pathway and *expanding the program* relative to student interest and growth is the dialectical tension which constitutes the personal layer of pedagogy.

In summary, this analysis of the personal layer of pedagogy has highlighted the importance of promoting agency for the learner and taking the learner as the main *Subject* of education. Allowing for a high level of autonomy of learning requires qualitatively differentiating the program. To see the outcome of learning as the development of the learner's identity is to emphasise the *humanistic and existential meaning of education* (Freire, 1996; Maslow, 1970). It challenges many of the arguments in STEM reports regarding the importance of measurable performance, standardised assessment and marketable skills. It also suggests a need for Tech Schools to fully engage with schools before and after in-house programs to have a meaningful impact on the lives of learners. In this way, Tech Schools could serve an aspirational role for students who do not fit the typical STEM profile of tech-savvy entrepreneurs.

(b) Lesson layer: Relational learning.

As human learning activities are social, during a lesson the students orientate their motives for learning towards a shared Object. This involves a transformation of their role from individual Subject, to participant in the lesson by becoming *a member of a community* of learners (Dewey, 1916/2010). It is a process of "intersubjectivity", a term used by Bruner to describe "how humans come to know each other's minds" (1996, p. 12). The cultural practices which the students engage in and co-create with the educators – such as specific routines and procedures, symbolic actions, joint usage of tools and the development of new roles – constitutes the praxis of the pedagogical situation (Freire, 1996). It consists of two interrelated aspects of pedagogy: establishing a *learning environment* which promotes active engagement in authentic practices and promoting a *democratic community* in which the students develop positive social identities through role-relationships with others (Dewey, 1916/2010; Mead, 1934).

The physical learning environment of a Tech School has been discussed extensively in part 1 of Section 2 of the literature review. It is worth noting a few points regarding active student engagement in *authentic practices* as this underpins the purpose of the learning environment. A Tech School learning environment embodies real practices from industry related to the use of technology and tools as "knowledge tools" for the purpose of education (Kalthoff & Roehl, 2011). The environment mediates between work and education by providing a range of rituals, routines and modes of using the space and technologies which are relevant to both contexts. The design thinking process is an example of an authentic work practice which serves as a *cultural script* for cueing interactions between students and the learning environment in a Tech School (Cole, 1996). Wartofsky refers to these mediating resources as "secondary artefacts" in specifying the cultural usage of primary artefacts such as technological tools (1979, pp. 200-201). Careful consideration of *secondary artefacts* which support the active engagement of students in authentic workplace practices using technology, underpins the educational quality of lessons in a Tech School.

Tech Schools have the potential to enact a progressive model of education by reframing the *social context of learning* through a new social milieu (Cole, 1996). Traditional school hierarchies of authority can be suspended within a Tech School as school teachers and students engage in learning for the sake of designing a solution to a problem, rather than "banking" knowledge from the curriculum (Freire, 1996, p. 46). As teachers and students co-construct knowledge as part of a community, they negotiate new roles, thereby challenging teachers to *expand their pedagogical self-concepts* as they attune themselves to students as leaders (Engeström, 1999). This can be an opportunity for students to explore new social identities as they step out of the institutional paradigm of schooling shaped by norms such as class, intelligence, gender and ethnicity (Duveen, 1997). The *relationships between people* become as important as the *relationships between concepts*, which places emphasis on integrating cognitive and affective dimensions of learning (González Rey, 2016; L. S. Vygotsky, 1971). Assessment of student growth as members of a community can be undertaken by the students themselves as well as teachers by drawing from the *personal and social capabilities* from the curriculum.

Tech School lessons can reframe traditional notions of pedagogy by placing emphasis on the *preparation of the learning environment* and providing *authentic work practices* to support the growth of student capabilities. Rather than teaching from the front, the development of quality resources can scaffold students' active engagement in routines, processes and their independent manipulation of technologies (Harel & Papert, 1991). Establishing a *relational notion of pedagogy* can challenge both students and teachers to grow as members of a community through new roles (Mead, 1934). It is through the internalisation of these social interactions requiring negotiation, empathy and reflection that students can develop technical capabilities as well as social identities (L. Vygotsky, 1978). This will require new forms of assessment that reorientate the curriculum towards the social construction and application of knowledge.

(c) Project layer: Collective learning.

The term "project" has been extensively used since William Kilpatrick's original formulation of a project in education as "a wholehearted purposeful act carried on amid social surroundings" (1918/2020). As Tech School projects tend to be group projects, the project layer described here is focussed on the *collective* employment of skills and capabilities needed to work as team. The project that the students undertake as designers of solutions to user problems, represents a shift in roles: initially from *individuals* in a program; to *participants* in the lesson and finally to *members* of a team. The project involves a division of roles with each team member playing their part in achieving a shared goal. Collective membership in a group project – either in education or the workplace – has been extensively studied by Leont'ev (1981) and by Engeström (2001). Shifting between *individual, relational and collective identities* is a common practice in the workplace. Yet, these psychological layers are not explicitly highlighted in education which can result in inappropriate pedagogical approaches.

The *collective layer* most closely resembles the existing paradigm of school pedagogy as the students' roles become interchangeable, skills become standardised and knowledge becomes generalisable. Skills related to task management and collaboration come to the fore. Learning is applied through the manipulation of tools, technologies and resources to solve problems, which can have meaning beyond the school through the selection of real industry and community issues. Each of these aspects of the project layer will now be outlined, beginning with the development of *group identity*.

As the students collaborate on a project, the Object of learning is shifted from satisfying personal motives to contributing to a group goal (Leont'ev, 1978). Aligning personal interests with the interests of other team members can be challenging as it requires an identity shift from "I", to "Me" (Mead, 1934) and then to "We". Yet, the process of de-emphasising the uniqueness of our identity allows for a *collective self-concept* which distinguishes the group from other groups (Brewer & Sedikides, 2001). This can foster collaboration between students from quite different backgrounds and with different interests by transcending their own experiences and values to take on common attitudes with others (Baldwin, 1986). Mead likened this process to a game where roles and rules of an organised community are internalised as a *generalised other*. Pedagogy which promotes collective learning through team-based projects, must invest time in supporting students to make the transition between the *individual self*, to the *relational self* and finally the *collective self*. Not only is it an important psychological consideration for group learning, it is necessary for the development of citizens who can collectively contribute to the betterment of a democratic society (Dewey, 1916/2010).

Asking students to commit to a group goal which may not directly satisfy personal interests, is not a trivial request, which relates back to Kilpatrick's notion of "wholehearted and purposeful" engagement by the student. As Mariane Hedegaard et al. (2012) note, the *societal purpose* underpinning the project needs to be related to the students' *personal motivations*. Tech School projects mediate this relationship by allowing students to pick the problem they wish to solve and to make explicit connections between learning and occupations. This creates a *professional purpose* for learning to use technologies, researching community issues and applying formal knowledge from the curriculum (Dewey, 1902/1971). While Leont'ev (1978) rightly notes that at the level of collective learning, tasks can be divided and completed with some degree of automaticity, his counterpart L. Vygotsky (1978) understood the importance of *engaging learners as conscious agents*. In this way, individuals commit to playing a functional role in a group project because they "project" their motives into the collective endeavour.

Just as a student project should have a purpose worthy of investing time, a similar argument can be made for *education as a type of project*. The dissection of education into separate subjects, step-by step curriculum and division of labour into tasks by teachers reflects a *collectivist approach to pedagogy*. Yet, teachers and students do not necessarily have a say in determining the outcome or purpose of the *project of education* which results in a system requiring coercion through authority and extrinsic incentives (Greene, 1978). If pedagogy becomes a mere technical process, it risks being automated. Maslow (1970) proposed that this could be avoided by centring education on problems, questions, functions and goals rather than methods, techniques, procedures and apparatus. As the *means* of labour and pedagogy become increasingly automated, the focus of industry and education should centre on the *purpose of the activity* in supporting the humanisation of the individual (Freire, 1994) and promoting humanity in society (Marx, 1847/2018). Marx's understanding of the risk and opportunities of automation are even more relevant today at the onset of the AI era, as they were in his time.

Summary of Layers of Pedagogy.

The pedagogical impact of the Tech School model of project-based learning has been analysed as a multilayered dialectic. By highlighting the distinctly different pedagogical focus at the layer of the *program*, the *lesson* and the *project* a more nuanced understanding of the object of pedagogy has been presented. These pedagogical layers have been aligned with psychological layers of identity which are the *individual self*, the *relational self* and the *collective self*. As human activity and participation in society results in a multilayered sense of self, education can support this development in the learner through an understanding of the social relationship between students, teachers, the community as participants in the project of education (Noddings, 2015). This was a common theme running through constructivist theories included in this section. Table 4 presents a summary of these constructivist theories which are further elaborated in Chapter 3 as an analytical framework for evaluating Tech School pedagogies.

Table 4
Key Themes from the Literature on Constructivist Pedagogies

Pedagogical layer	Key theme
Personal layer *Individual learning*	The program should promote student agency and focus on the personal growth of students (Piaget, Dewey) Teachers should foster personal connections between the learning program and the students' life experiences (Hedegaard et al.) Task differentiation supports development along an established pathway based on student need (Vygotsky). Program differentiation allows for multiple pathways and outcomes based on student interest (Dewey).
Lesson layer *Relational learning*	Students and teachers become members of a learning community though intersubjectivity (Bruner, Vygotsky) Diverse forms of assessment are needed to evaluate the social acquisition of cultural practices (Cole) Authentic workplace practices need to be scaffolded using secondary artefacts such as routines, roles and practices (Wartofsky) Focussing on developing an active learning environment reduces the need for lectures (Dewey)
Project layer *Collective learning*	Student engagement in team membership involves the internalisation of generalisable roles (Mead) The project requires a division of labour involving specific skills using tools (Leont'ev) Working in a team of diverse learners allows for different skills and values to be synthesised for the development of consciousness (Vygotsky; Freire) Relating the project to personal interest and societal issues expands the focus of education (Dewey, Kilpatrick)

Part 3. Professional Learning (PL) for Teachers.

Tech Schools focus on two main areas of PL. First, ICT skills to support teachers' *technological confidence and capacity* which is fundamental to new pedagogies (Ertmer, 2014; Ertmer, Ottenbreit-Leftwich, & York, 2007). Second, familiarising teachers with the *design thinking process* for structuring projects. There is scope for formalising this aspect of PL in mentoring teams of teachers from schools in how to link projects to the curriculum for integrated units of work across multiple subject areas (Rennie, Venville, & Wallace, 2012). The term "professional learning" (PL) is used instead of "professional development" (PD) to signify a transition from one-off workshops to ongoing support provided by Tech Schools for teachers. When referring to the literature the most relevant term is used.

Regarding technology, Baker (2009) recommends that PD be differentiated to teachers' different levels of technical ability and that a network of ongoing support be established for teachers in schools. Once teachers become comfortable with using diverse technologies, technology can serve as a common platform for linking multiple disciplines (Herro & Quigley, 2017). An example is media software technology, which can be used as a mediating tool to connect Tech school programs with in-school STEAM programs through joint communication and creation.

Tech Schools can mediate between a network of STEAM specialists, as well as provide a base of resources for teachers. The establishment of STEM networks has become a valuable source of support for teachers both overseas (Aslam et al., 2018; Bybee, 2013) and within Australia (Australian Industry Group, 2017; Education Services Australia, 2018; Office of the Chief Scientist, 2016b). In building on theory by Lave and Wenger (1991), Aslam et al. (2018) refer to this network as a form of community of practice (CoP) where teachers feel that they can identify themselves as part of the scientific community. Tech Schools play an important mediating role in creating a STEAM CoP by connecting industry, schools, and tertiary institutions like university. This allows for innovative redesign of the structure and vision in each of these institutions as a collaborative project (Cingel Bodinet, 2016; Ge et al., 2015).

PL for shifting educator mindsets and school cultures.

As the focus of teaching transitions from *covering the curriculum* to *fostering student growth*, Korthagen (2017) believes that professional development for teachers should also undergo the same shift. PD organisers and pre-service teacher training can better meet the learning needs of teachers by developing an understanding of the motivations and beliefs of teachers, particularly the relationship between theory and practice (Korthagen, 2017). While PL through educator attendance at Tech Schools can provide specific STEAM skills and gradually shape educator beliefs, innovative teaching practice requires the *ongoing professional learning that occurs in praxis* (Fullan, 2007).

Establishing an environment and culture which support teacher risk-taking and experimentation with new pedagogies, will require Tech Schools themselves to operate as *learning organisations*, where learning occurs at all levels (OECD, 2016). Process-over-product is embedded within the social fabric of Tech Schools in: designing programs; rearranging space to adapt to new needs; updating equipment; and promoting risk taking for creativity in teaching and learning. In this way, Tech Schools and secondary schools can collaboratively develop a *professional learning community* (PLC) to plan, implement and review new pedagogies. Further, through engagement with industry on projects, the notion of PLC is broadened to become an ILC (inter-institutional learning community). The notion of ILCs in education builds on research by (Dille & Söderlund) in the field of project management where ILCs refer "to those projects that involve actors representing different institutional environments (2011, p. 482).

Shifting traditional pedagogical beliefs of educators.

Educator beliefs are a challenging construct to study as they are a mix of cognitive and affective processes. These may be related to knowledge, experience, motivations and philosophies which are constantly adapting to environmental cues (Ertmer, 2014; Pajares, 1992). Teacher beliefs significantly impact on their pedagogical approaches, and the choices they make in responding to contextual affordances and student behaviours (Korthagen, 2017). Kagan notes:

> Teacher belief appears to arise out of the exigencies inherent in classroom teaching, it may be the clearest measure of a teacher's professional growth, and it appears to be instrumental in determining the quality of interaction one finds among the teachers in a given school (1992, p. 85).

Further, teacher belief becomes pronounced in project-based learning interactions beyond their subject domain. For example, research by ACARA (2016) into interdisciplinary STEM projects, reports that teachers experience uncertainty with regards to the incorporation of specific content into projects. In addition, teachers feel challenged to: manage group dynamics; facilitate student learning at different stages of their projects and relinquish their role as leader (ACARA, 2016). These challenges are more readily overcome if teachers have adopted a perception that integrated STEM teaching is *pedagogically valued* as they are more willing to persevere and invest time in planning and debriefing with other teachers. Experiencing success through a Tech

School program can promote a STEAM "growth mindset" for educators and translate into pedagogical experimentation back in the classroom (Dweck, 2017).

The shift from teachers being *authorities* on valued knowledge to *learning alongside students* can be problematic – particularly in the fields of STEM and STEAM – as knowledge is negotiated rather than fixed. This can result in teacher reluctance to engage in practical activities due to a lack of confidence (Fernández-Limón, Fernández-Cárdenas, & Gómez Galindo, 2018). Yet, Hetherington and Wegerif note that, if teachers can overcome their feelings of insecurity and vulnerability, the experience of shared learning can provide opportunities for "material-dialogic pedagogy" with students discussing ideas with their teachers using concrete resources (2018, p. 40). According to Korthagen (2017) more research is needed to understand *how teachers learn*, including their beliefs and behaviours. This is pertinent to the success of Tech Schools in providing effective PL for educators as life-long learners (Field & Leicester, 2001).

In summary, professional learning is an impactful aspect of Tech Schools for mediating changes to teachers' praxis. Currently the predominant focus of Tech Schools is providing short PD sessions on developing skills in technology and using the design thinking process to plan and teach projects. Yet, Tech Schools could play a more foundational role in supporting teachers if PL was integrated into teaching at school. An example of this is Tech Schools which have been developing STEAM communities of practice (CoP) which encourage teachers, industry representatives and education researchers to meet and discuss opportunities and challenges in integrating STEAM projects in schools. In this mediating role, Tech Schools provide cultural development in schools and establish a broad network of motivated leaders who support structural changes to education. This relates to the fourth impact of Tech Schools in connecting schools to community.

Part 4. Authentically Connecting Schooling with Industry and Community.

Tech Schools as mediating organisations have a unique position in sitting between education, community and industry. Each Tech School develops a *cultural identity* based on the local relationships between schools and other institutions related to health, transport, manufacturing, construction, arts and community. Thus, one of the most significant impacts of Tech Schools is in promoting i*nter-institutional engagement* at a local level. Within the field of project management, engagement between institutions and organisations through inter-institutional learning communities (ILC) is increasingly being researched due to the complex nature of business in the twenty-first century (Dille & Söderlund, 2011). Tech Schools as mediating organisations between school-community and industry represent a new context for ILC research.

Tech Schools' mediation of school-industry engagement has a utilitarian role in addressing the vocational purpose for education. It also has a social role in promoting *co-design* of programs between teachers, community leaders and industry representatives. This can broaden the types of educational experiences which students partake in.

The aspirational and vocational focus of Tech Schools.

Fostering partnerships between education and industry through project-based programs has become a STEM-education focus to increase student awareness of career pathways. According to Baxter "some young people appear to have insufficient information about the labour market and about the pathways they need to take in order to achieve their desired jobs" (2017, p. 29). Promoting career aspirations is especially important for students "who are less motivated to explore different options, who are less certain about their own abilities, whose school outcomes are poorer, or who do not have access to supports that could help them identify career options" (Baxter, 2017, p. 30). For students who are unsure of the diverse range of professional careers available, Tech Schools can play an aspirational role by providing authentic experiences related to local industries.

Utilising the potential of industry for student engagement in real world problems, especially for "student cohorts underrepresented in STEM fields" is one of 10 of recommendations by Education Services Australia (2018, p. 15). Yet, for teachers in schools, making authentic connections between school and industry can be daunting, and if not well organised can have a negative impact on student engagement and learning outcomes (Australian Curriculum and Assessment Reporting Authority, 2016). The Australian Industry Group explains that "Much of this activity is largely uncoordinated and is at times unfocussed and haphazard across states, schools and teachers" (2017, p. 18). Further, many STEM activities are extra-curricular and not integrated into the school schedule, thereby relying on teachers and parents to volunteer their time. This can also involve costs to be covered by schools, if funding is not available. According to the Australian Industry Group (2017) this is not a sustainable approach.

Both the Australian Industry Group and Education Services Australia, recommend the use of an *intermediary organisation* to broker school-industry connections. This mediation can involve: contacting suitable industries; providing communication, support and professional development for teachers; and developing research tools such as surveys (Australian Industry Group, 2017). Tech Schools are purposely designed for this intermediary role by drawing together multiple stakeholders as well as having ongoing government funding for resources and hired expertise. They provide multiple platforms for school-industry-community partnerships such as: workshops; community events; competitions; industry networking sessions and other STEAM outreach programs. *Tech Schools as hubs*, provide a context for meetings between industry, community and schools which foster relationships between diverse sources of expertise, available resources and mutually supportive aims. While collaborations between local industry and local schools already exist in the form of incursions, excursions, placements and work experience, the logistical process of organising these exchanges can be overwhelming and a deterrent both for schools and industries (Australian Industry Group, 2017).

Tech Schools as *mediating organisations* provide a formalised agreement between existing members with a common mission by *acting as a broker* (Australian Industry Group, 2017). Teachers may utilise their local Tech school as an opportunity for networking with education-minded industries, leading to direct partnerships between schools and industry through the development of a CoP (E Wenger, 1999). Further, involving the community at large in the Tech School initiative can have a positive influence on raising public interest in science (Montgomery & Fernández-Cárdenas, 2018; Watermeyer & Montgomery, 2018). Through successful partnerships, teachers can develop new skills in working in a *distributed learning environment*, enabling students to utilise professional and educational resources beyond their school (Education Services Australia, 2018).

Co-design through STEAM: The social creation of programs.

Tech school STEAM programs are developed through a co-design process between: educators; students; industry representatives; community members and experts from various disciplines. Involving these stakeholders in a common endeavour allows for different world views and common themes to be explored through *co-operative inquiry* (Gatenby & Cantore, 2018b). A Tech School as a makerspace provides an ideal environment for co-designing as it promotes situated learning experiences with low-tech and high-tech technologies (Harel & Papert, 1991; Lave & Wenger, 1991).

Central to the delivery and the development of Tech School programs is the design thinking process. This has been discussed in relation to student learning and teacher professional learning. Additionally, design thinking is powerful for the co-design of programs and reimagining school structures (A. Diefenthaler et al., 2017). During a Tech School co-design workshop, industry representatives engage in a condensed version of the learning programs which the students will undertake. Adopting a student-perspective can encourage industry representatives to think beyond *business as usual* and consider the broader impacts of their industry on the local community (Cababa, 2017; Meinel & Koppen, 2015). Thus, education-industry-community collaboration can result in program innovations which reframe student learning, teacher perceptions and industry practices.

An example from the literature of the benefits of bringing together members from different domains of knowledge and experience is the “STEAM Professional Learning Lab” (Kelton & Saraniero, 2018, p. 56). Researchers Kelton and Saraniero note that tension and synergy emerging from partnerships between practitioners of diverse disciplines “can be highly generative for collaborators, by catalyzing new ways of looking at a problem, bringing limiting assumptions to the foreground, or drawing different perspectives together” (2018, p. 55). Whether collaborations occur between institutions, teachers from different school departments or students with different backgrounds; one of the key benefits is the opportunity for individuals to reflect on their own practices through new perspectives, which applies equally well to science or arts educators (Rolling, 2016). For this reason, STEAM co-design is an amplification of *social constructivist theory*, whereby people expand their individual understanding through diverse interactions with others to collaboratively construct a new body of knowledge greater than any individual could achieve alone (Engeström, 2016).

Opening-up education to encompass learning from the community and industry is identified throughout the literature as an ideal conception of education, yet one which has hardly progressed since its promotion by John Dewey at the start of the last century. The co-design of school programs can provide much needed authenticity to the curriculum, as a pathway towards preparing students for career opportunities and addressing societal challenges. Tech Schools as mediating organisations provide the perfect atmosphere and structure for collaboratively constructing new knowledge through diverse inter-institutional relationships between STEAM industry, education and community.

Summary of Section 2: Tech School impacts.

Section 2 provided both a cultural and a technical evaluation of the Tech School initiative. This educational focus on Tech Schools as progressive models of education serves as a contrast to Section 1 which provided a political context for Tech Schools as part of the national STEM strategy. Tech Schools as part of a cultural change to education was analysed through the theoretical lens of constructivism.

The potential of Tech Schools for transforming schooling towards a more socially relevant and personally meaningful model was examined in terms of four impacts on education. First, Tech Schools as *innovative learning environments* provide examples of alternative infrastructural and pedagogical considerations for designing new school environments. Second, the redesign of learning experiences was extended through an analysis of how Tech Schools *develop transdisciplinary programs and utilise constructivist pedagogies*. Third, the impact of Tech Schools on education through teacher PL was extended to consider the potential of Tech Schools to support cultural change in schools through a *STEAM inter-institutional learning community* (ILC). Finally, the notion of an ILC was formalised as Tech Schools mediate between education, industry and community to *co-design STEAM programs and projects*. These four impacts – reflecting dimensions of Tech Schools as *mediating organisations* – are empirically studied using case studies in Chapter 5. The four potential impacts feed into two dialectically interrelated Tech School activities: developing and trialling project-based pedagogies and programs (research-orientated activity) and institutional engagement between schools, community and industry (politically-orientated activity). Both dimensions of a Tech School structure the conceptual framework for the study in Chapter 3 and the analytical frameworks used to analyse case study data in Chapter 6.

Chapter Conclusion

This review of the literature has addressed two interrelated aspects of Tech Schools as *mediating organisations*. First the *political role* of Tech Schools in supporting the STEM education strategy which has been critiqued from a sociological perspective. Tech Schools could reframe the reductionist paradigm of STEM by orientating technology industries towards meeting humanistic needs of society. STEAM education has been promoted as a means of achieving this holistic goal.

The second aspect of Tech Schools evaluated was the *educational potential* of Tech Schools to shift ingrained structures of mainstream schooling which are out of step with developments in industry and society. Through the redesign of the learning environment, developing transferrable STEAM programs using constructivist pedagogies, promoting cultural change in schools as learning communities and fostering partnerships between schools, industries and the community, Tech Schools have the potential to shift outdated structures of mainstream education. Yet, each of these impacts needs to be evaluated with evidence. The remainder of the thesis provides methods of collecting evidence and rigorously evaluating the success and limitations of the Tech school model for educational change.

The structure of the literature review in two main sections represents *the dialectical relationship between the political and the educational function of Tech Schools*. This dialectical conceptualisation of Tech Schools as mediating organisations serves as a conceptual framework for the study. Chapter 3 presents the conceptual framework as well as analytical frameworks focussed on (1) Tech School project-based pedagogies as a dialectic between teaching and learning, and (2) Tech Schools as mediating between schools and industry/community. Chapter 4: Methodology outlines how these analytical frameworks are utilised to examine data collected through four case studies on the impacts of Tech Schools.

Finally, this review of the literature has highlighted a major challenge in researching Tech Schools, which is: synthesising the breadth of political and philosophical Objects which inform Tech Schools as mediating organisations and the multiple supports that they provide for teachers to overcome challenges of implementing project-based learning in their schools. Thus, the study of interrelated dimensions of Tech Schools and their diverse mediating activities, is not well-suited to the traditional scientific research paradigm (Cole, 1996). For this reason, a conceptual framework is developed from Cultural-historical activity theory (CHAT) which has been proven effective in researching complex socio-cultural contexts in education (Cole, 1996; Engeström, 1999; L. Vygotsky, 1978). The conceptual framework will be utilised to critique the Tech School initiative from a *theoretical perspective*, and also propose how Tech Schools can support change from a *pragmatic perspective*.

Chapter 3: Frameworks

Background to the Frameworks

This chapter builds from key themes which emerged through analysis of literature in Chapter 2. The division of Chapter 2 into two sections to examine Tech Schools from a *sociological perspective* and from a *constructivist pedagogical perspective*, is also used to structure the conceptual framework for the research study. For this reason, the conceptual framework is immediately presented to allow for a visual reference. Following this introduction, the full theoretical background for the conceptual and two analytical frameworks will be presented.

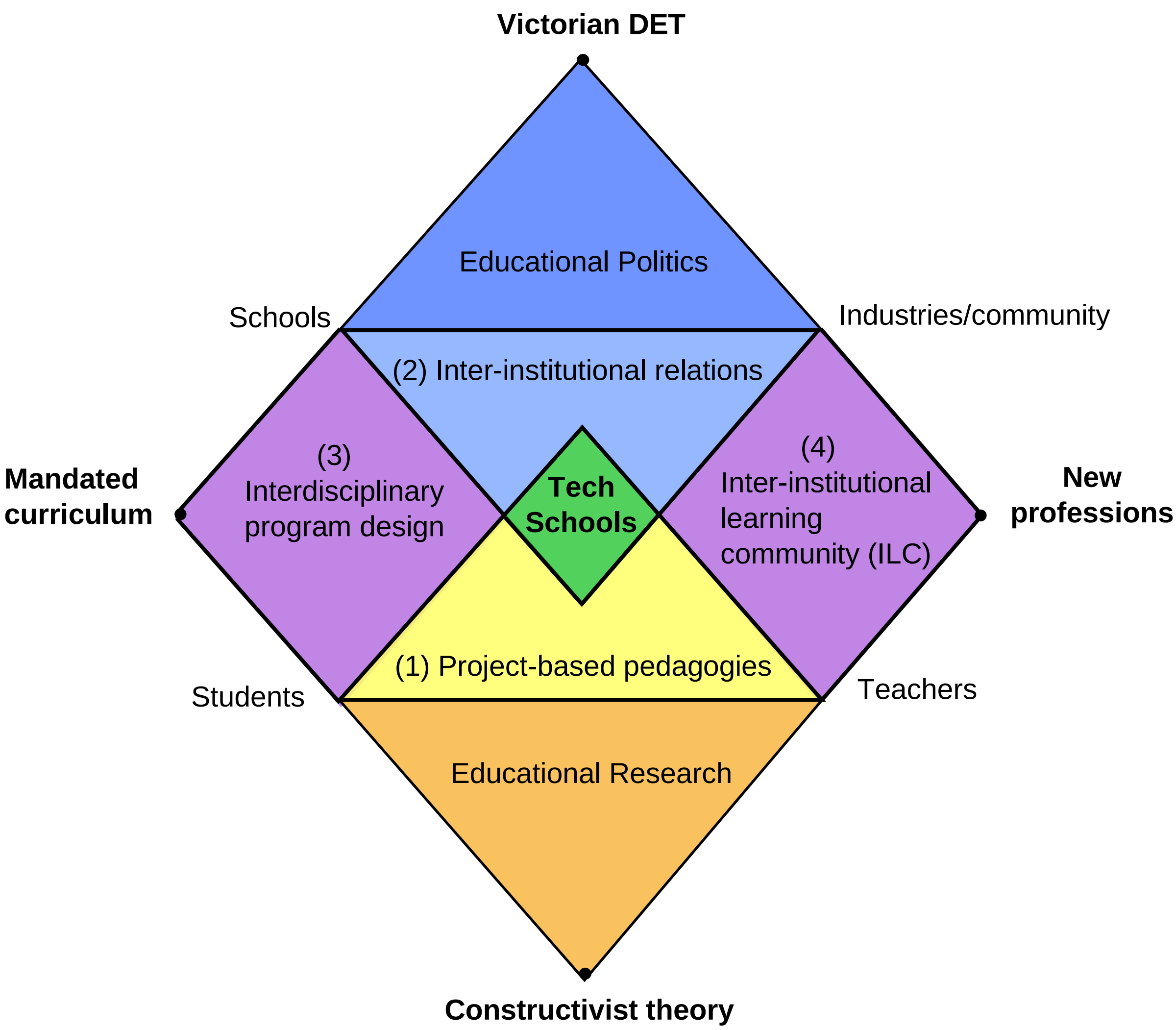


Figure 2. Conceptual framework for the research study on Tech Schools

The conceptual framework explained.

The conceptual framework was informed by key themes outlined in the literature review and modified throughout the study based on the case study findings. The conceptual framework served the purpose of visually representing the dialectical relationships between different Tech School activities as well as relating theoretical insights to empirical data for analysis. These applications of the conceptual framework are supported by Leshem and Trafford (2007). Colour coding visually represents the relationships which connect key terms from the literature review. To explain the conceptual framework, key terms are italicised and colour codes are referred to in brackets.

Tech Schools as "mediating organisations" (green diamond) are a dialectic between two fundamental activities: (1) *project-based pedagogies* (pale yellow triangle) and (2) *inter-institutional relations* (pale blue triangle). Sections 1 and 2 or the literature outlined the broader political and theoretical influences on these activities.

Section 1 of the literature review established the political function of Tech Schools in mediating between schools and industry/community through *inter-institutional relations* (2). This Tech School activity is overseen by the *Victorian DET* (Department of Education and Training) as a form of *educational politics* (dark blue triangle). At its broadest reach, the DET can be seen as mediating between the *mandated curriculum* and *new professions* (shown as the top boundary of the large diamond) to ensure that education is relevant to developing professions as a result of the 4IR.

Section 2 of the literature review drew upon constructivist theory to outline how Tech Schools design programs which promote interdisciplinarity and utilise pedagogies which dialectically relate teaching and learning through *project-based pedagogies* (1). This pedagogical function of Tech Schools is informed *by educational research* underpinned by *constructivist theory* (dark yellow triangle). At its broadest reach, constructivist theory is relevant to reorganising the *mandated curriculum* to more authentically reflect the requirements of *new professions* in the 4IR.

In this way, the overlapping triangles which create the central green diamond representing the local mediating activities of Tech Schools, mirror the larger external diamond representing the broader theoretical and political context of Tech Schools. These diamonds represent the construct of Tech Schools as *mediating organisations* which mediate the dialectical relationships within a local institutional-pedagogical layer and at a broader political-theoretical layer of education.

The four impacts of Tech Schools on education outlined in section 2 of the literature review can be seen as a pragmatic approach to mediation between politics and research in education. While these impacts were divided into four parts, they are interrelated and could be studied as different combinations. For example, in the literature review, program design and pedagogy were connected, while the Tech School learning environment and interinstitutional relations were examined separately. Alternatively, one could study the relationship between pedagogy and learning environment as a unit of focus and how the design of programs relates industry and schools as a unit. The conceptual framework organises the key themes according to a system which builds internal theoretical consistency and also helps to explain the empirical research findings (Leshem & Trafford, 2007). This reflects a constructivist research paradigm, which is explained in Chapter 4.

For this research study, the conceptual framework summarises the four mediating activities of Tech Schools as:

1. Project-based pedagogies (pale yellow triangle)
2. Inter-institutional relations (pale blue triangle)
3. Interdisciplinary program design (purple triangle)
4. Fostering an inter-institutional learning community (purple triangle)

Activities 1 and 2 have been described as emerging from the interrelation of politics and theory which informed the dialectical construct of Tech Schools as mediating organisations. Activities 3 and 4 can be seen as processes which connect activities 1 and 2. Through interdisciplinary program design (3), the *mandated curriculum* is related to the activity of engaging *students in project-based learning* (1) and the activity of encouraging *schools to connect with industry and community* (2). Similarly, through an ILC (4), *new professions* in industry and in education are related to activity 1(with an emphasis on how teachers can apply industry concepts to project-based pedagogies) and activity 2 (with an emphasis on providing industry and community with opportunities to engage with schools).

The dynamic relationship between these four mediating activities constitutes the pragmatic role of Tech Schools which is empirically researched through case studies, presented in Chapter 5: Results. To support the analysis of key themes emerging from the case studies, two analytical frameworks have been developed. One analytical framework is focussed on *project-based pedagogies* (1), while the other is focussed on *inter-institutional relations* (2). This analysis is undertaken in Chapter 6 in the form of cross-case analyses. These analytical frameworks are elaborated later in this chapter.

In summary, the conceptual framework was used to examine the relationships between the role of school, industry, students and teachers relative to the broader constructs of the mandated curriculum, The Victorian DET, new professions and constructivist theories of education. This constitutes the substance of discussion in Chapter 7: Conclusion.

Theoretical Foundations for the Frameworks

Lev Vygotsky's theory of *mediated action* was foundational in developing the frameworks. L. Vygotsky (1978) considered human thought as distinct from cognition of other animals – including non-human primates – in that human actions could be mediated through the use of tools allowing for an indirect method of attaining an object. This is represented in Figure 3.

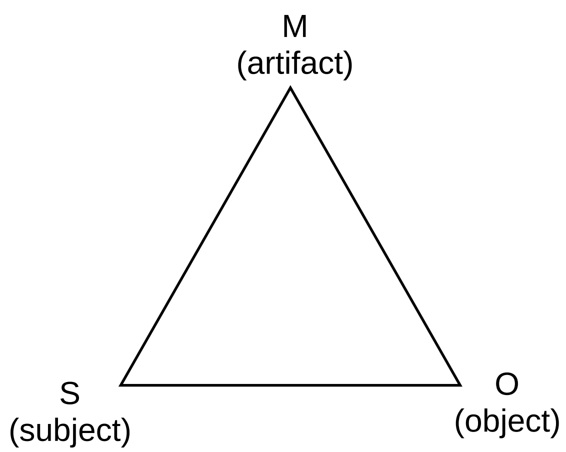


Figure 3. Vygotsky's model of mediated action.

It should be clarified, that this model is an adaptation by Michael Cole (1996, p. 119) of Vygotsky's model of mediation between stimulus and response (1978, p. 40). Cole's representation of the mediating triangle shows that, when a person as a Subject

(S) cannot directly achieve their goal or Object (O), they use an indirect method to problem solve. Note the capitalisation of "Subject" (person) and "Object" (goal) to distinguish them from the more common usage in education of the words "subject" (discipline) and "object" (thing). The indirect method involves the use of mediating tools and artefacts (M). Regarding mediating tools, humans not only use hand tools to achieve tasks, but through the organisation of activity and learning, these tools have become increasingly abstracted from the action at hand. They have become cultural artefacts such as signs and symbols. Vygotsky (1962) uses the example of language as a *social mediating tool* to indirectly achieve a goal.

Of central importance to education, is that skill and knowledge of how to use mediating tools can be historically transmitted through learning from one generation to the next through internalisation of social interactions (Cole, 1996). This is achieved through a reification of symbolic knowledge using artefacts such as written texts for language transmission, formulas and theories in science, equations in mathematics as well as other specific knowledge which underpins different fields of knowledge (Daniels, 2016). The equipment, rules, texts and theories are cultural artefacts which serve as mediating means in the progress of society through *zones of proximal development* (Engeström, 1999). The social organisation of activity into paradigms has enabled ongoing societal progress in developing cultural tools to overcome natural limitations of space and time. Sending a Rover to Mars and instantly communicating across the world via the internet are examples of the exponential development of mediating artefacts allowing humans to extend their Objects almost without limit. Whereas Vygotsky focussed on language as a predominant symbolic mediating artefact, contemporary progress increasingly draws on data-driven algorithms as computers have become the predominant mediating artefact for socio-technological progress. The contested relationship between societal and industrial progress through technology was discussed in depth in Chapter 2.

Elaborations of Vygotsky's triangle.

Vygotsky's triangle of mediated action has been used in education to consider how socio-cultural mediating artefacts can scaffold student learning through a zone of proximal development (ZPD) to promote cognitive development through internalisation (Davydov & Kerr, 1995). Vygotsky's theory has also been elaborated to consider how the collective organisation of people into groups with different roles constitutes particular types of *activity* which can greatly improve the success of Subjects to achieve complex Objects (Leont'ev, 1978). Engeström (2016) extended Leont'ev's concept of activity by considering the dialectical relationship between individuals and communities in terms of internal contradictions between the Object of activity and the division of labour based on rules. This field of research called Cultural-historical activity theory (CHAT) has been explored and elaborated across three generations: First, Vygotsky's cultural-historical theory, second, Leont'ev's activity theory and third, Engeström's expansive learning. The visual heuristic of Vygotsky's triangle has been reworked by a number of contemporary CHAT theorists as conceptual frameworks for qualitative research. Notable examples include:

- Yrjö Engeström's Second and Third Generation CHAT activity system models (1993, pp. 1-46)
- Michael Cole's Question-Asking-Reading (QAR) model (1996, pp. 274-278)
- Anne Edwards Joint Action on an Object Relational model (2005, p. 178)
- Stenild and Iversen's General Model of the Dynamics of IT-Supported Motivation (2012, p. 145)
- Harry Daniels' Dominance in Networks of Activity Systems Through Time (2012, p. 205)
- Katsuhiro Yamazumi's Hybrid Activity as Mediating System (2009, pp. 45-47)

This research study follows a similar process to the above theorists by elaborating on the mediating triangle. Yet, unlike many contemporary CHAT theorists the conceptual framework has been constructed from Vygotsky's original theory rather than second and third generation elaborations. It extends Vygotsky's heuristic in building from a "mediating artefact" to a dialectically constituted "mediating context". This is represented in Figure 4.

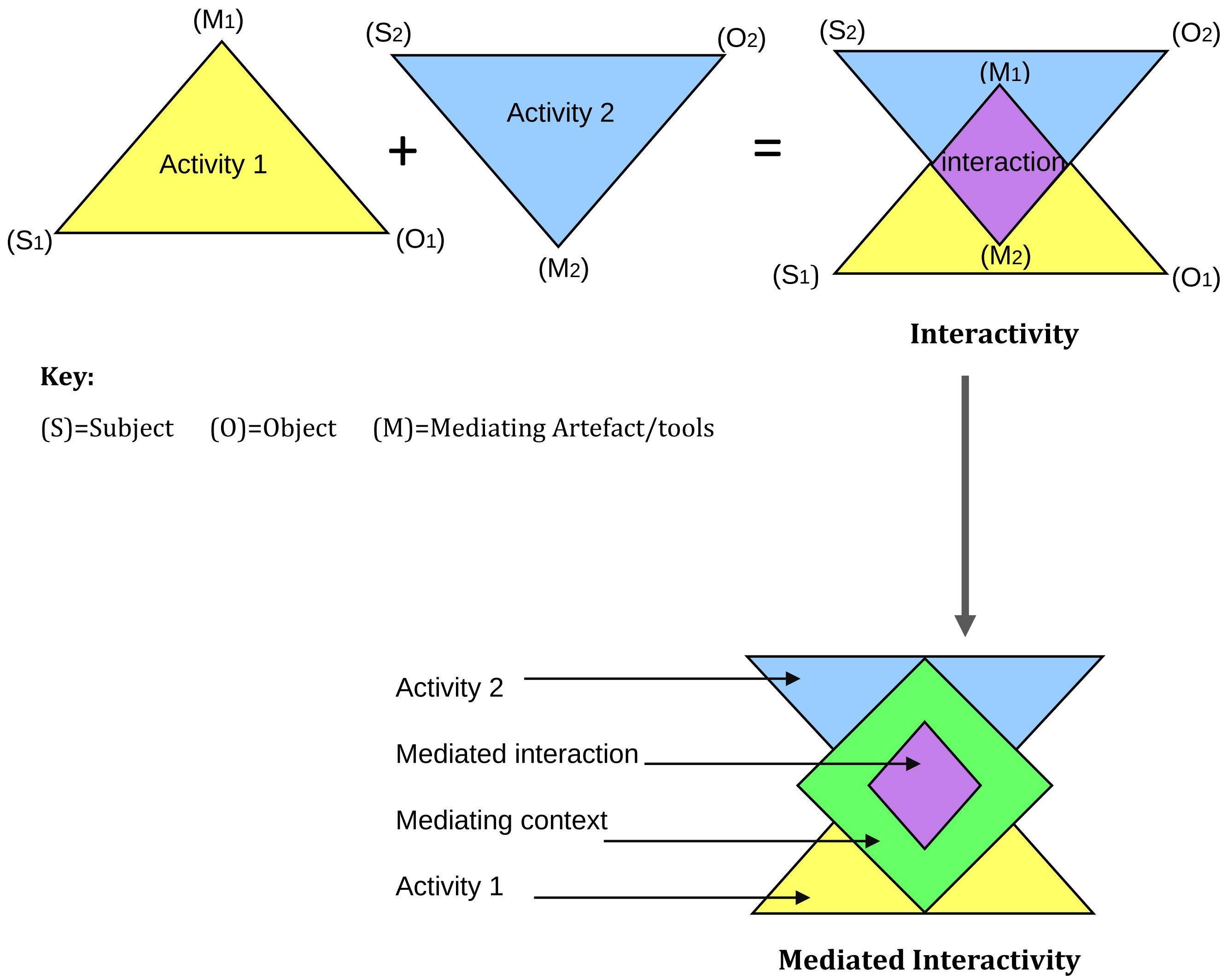


Figure 4. Dialectic of a mediating context through interrelated activities.

Within the scope of this study on Tech Schools, the term “mediating organisation” is used instead of “mediating context” to conceptualise the types of *institutional interactions* mediated by Tech Schools. The conceptual progression from Vygotsky’s triangle is that mediation is not only a matter of dialectically relating a Subject with their Object. It is often a matter of dialectically relating two activities consisting of different Subjects and different Objects. Examples of this dialectical interactivity in this research study include: the pedagogical activity of teachers and students analysed (case study 1); the interrelated activity of industry and schools (case study 3). These two forms of interactivity –mediated by a Tech School- constitute the basis of the two analytical frameworks used for cross-case analysis in Chapter 6.

The interrelation of these activities can be considered using the analogy of a knot. Knots contain tensions. These tensions can be positive in a social sense such as the interpersonal relations formed between stakeholders which Engeström refers to as "knotworking" (2001, p. 147). While *networking* may involve interactions aimed at mutually meeting individual Objects, through the process of *knotworking*, the Objects of the stakeholders become *dialectically entangled*. Changing the Object of one Subject influences the Object of the other. For example, the Object of a teacher will change depending on the Object of a learner if the pedagogical interaction is dialectically knotted/entangled. While the dialectical tension can be positive it can also be negative when the Objects of stakeholders are conflicting. The dual function of mediating tools to support the attainment different Objects of learning and teaching in tasks may cause tensions which are difficult to discern, yet Vygotsky's theory can help. By elaborating on Vygotsky's theory, two analytical frameworks were designed which focussed on the dialectical tension between stakeholders and the role of a Tech School as a mediating organisation.

(i) Mediated interactions between individuals.

Analytical Framework 1 examines the mediated *relationship between learning and teaching* in Tech School project-based pedagogies. From an individual Subject perspective, the framework represents some key aspects of Vygotsky's theory of learning through social interactions.

From a pedagogical perspective, when Activity 1 is undertaken by a teacher with a particular developmental Object and Activity 2 is undertaken by a student, the mediated interaction of collective activity promotes *expansion of individual consciousness* for the learner and the teacher (refer to figure 4). Yet, pedagogy can also be employed as a means of *extrinsically shaping* learner thinking by binding the learner to accepted conventions and conceptions of significant knowledge, pre-determined by educators and more broadly society (Duveen, 1997). This dialectical learning tension involving the process of identity formation, and knowledge construction within the boundaries dictated by education, was central to examining the Tech School STEM Initiative. It was hypothesised that the broader tension between the political Object of the Tech School STEM initiative and the constructivist theory of pedagogy promoted in

Tech School projects could impact on the interactions between educators and students in Tech School programs. This relationship between the broad and local tensions in Tech School mediation are examined using the conceptual framework in Chapter 7.

(ii) Mediated interactions between institutions.

Analytical Framework 2 examines how Tech Schools mediate the mutual development of industry/community and education through inter-institutional relationships. When Activity 1 and Activity 2 in Figure 4 represent institutions such as industry and education, then the study of multi-layered *conscious action* is replaced by the study of multi-layered *institutional activity*. The development in soviet CHAT from Vygotsky's focus on individual consciousness to Leonte'v's focus on activity represents a broadening of the unit of analysis to relate individual consciousness to collective activity (Engeström, 2001). While the proposed framework does examine the relationship between individuals and the institutional activity (or practice) they participate in, the central unit of analysis becomes the mediated relationship *between representative stakeholders of institutions*.

Dialectical tension as a force to promote change through mediated interaction between stakeholders, is both relevant at a *pedagogical level* and at an *institutional level* of education. Tension creates the necessary conditions for development as stakeholders negotiate, reflect and expand their objects through learning interactions. In expanding their own Objects, these stakeholders further expand the learning dialectic. Engeström (2016) refers to this process as "expansive learning". Yet, this mediated expansion of learning by stakeholders can be met with resistance as it challenges the existing bureaucratic relations in industry and education (Serdyukov, 2017).

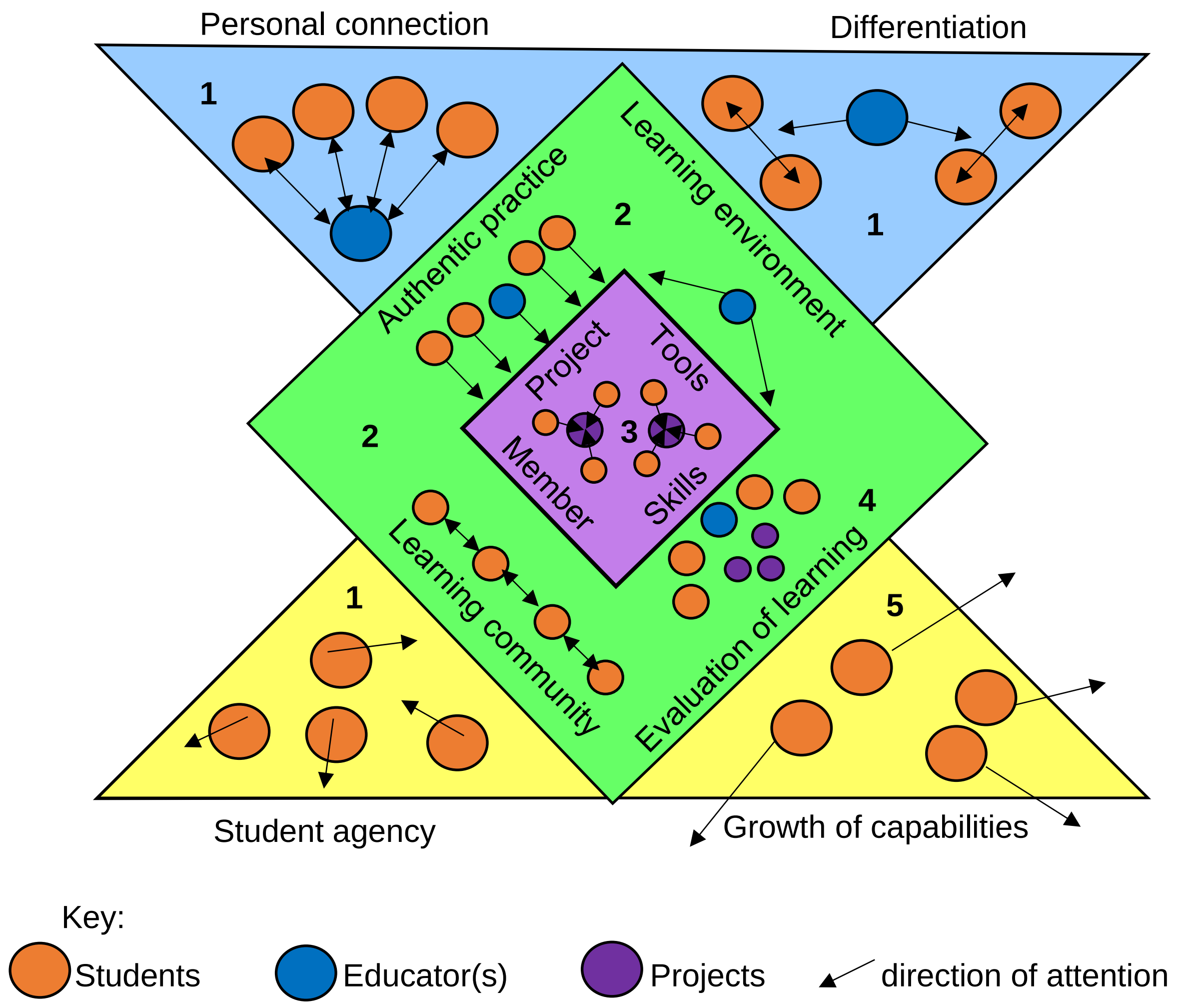
Three examples are presented in this chapter of the interrelation of activities in Tech Schools as mediating organisations. These examples represent three contextual layers (or levels) of mediation. First: the context of mediating the dialectic of teaching-learning in *project-based pedagogy*. Second: mediating the dialectic of *school-industry relationships* for expanding the activity of schools. Third: mediating the dialectic of *educational politics and research* for transforming education. Examples 1 and 2 are elaborated as analytical frameworks, while example 3 combines 1 and 2 into the conceptual framework representing a broader context of Tech School mediation. For clarity, these examples are presented separately beginning with the analytical frameworks.

Analytical Framework 1: Examining Project-based Pedagogies.

The dialectic of pedagogy was discussed in Section 2, part 2 of the literature review regarding the interrelation between teaching and learning across three layers: *personal*, *relational* and *collective*. Through engagement in a project, teachers and students undertake different interrelated actions, which creates a pedagogical dialectic. This distinction between the actions of each of the stakeholders/Subjects shown in Figure 4 (S1 & S2) and their dialectical interactivity is important because each participant acts partly according to a *common collective Object* and partly according to *different personal Objects* (O1 & O2).

These personal Objects may be determined by stakeholder participation in other activities. For example, pedagogy as enacted in a Tech School involves students, teachers and Tech School educators. The students have their own Objects related to satisfying personal and social motives for learning. Part of the students' Objects are also related to their participation in the activity of learning in their own schools which may be shared by their visiting class teachers. The Tech School educators have their own personal motives related to teaching, as well as the Object of delivering a successful program. The Object of the program is informed by the goals of the Tech School initiative.

Tech Schools as mediating organisations embody these interrelated Objects and are successful in terms of how well they mediate between them. The mediating artefacts (or tools) utilised in a Tech School have a *dual purpose* of mediating the politico-educationally informed activity of the Tech School educators and the socio-educationally informed activity of the students. The dialectic between teaching and learning in Tech Schools is presented in Figure 5: Analytical Framework 1 which was used to analyse data from case study 1 in Chapter 6 of this thesis.



Layers of pedagogy	Criteria for evaluation	
	Main learning focus	Main teaching focus
Personal layer: Individual learning	Student agency Growth of capabilities	Personal connection Differentiation
Lesson layer: Relational learning	Learning community Evaluation of learning	Authentic practices Learning environment
Project layer: Collective learning	Team membership Diverse skills	Design of project Tools and resources

Figure 5. Analytical framework 1: Tech School mediation of project-based pedagogies.

Analytical Framework 1 explained.

Figure 5 is a synthesis of key theories from the literature review into an analytical framework used for analysing case study results on program design and pedagogy. It represents the three layers of pedagogy utilised in project-based learning programs. The key themes from these layers are organised in a table and colour coded to relate to the diagram. An elaborated version of the table was used for a primary analysis of observation data from Tech School programs. This table is presented at the end of the Chapter 4. Figure 5 is used for secondary analysis, to consider the pedagogical choices across layers of pedagogy made by Tech School educators throughout the two to three-day programs. In addition, the analytical framework was used to compare two Tech School programs with a secondary school STEAM program. Analytical Framework 1 was also used for triangulating teacher and student interviews, survey data and observations. This is presented in the Chapter 5 Results.

Analytical Framework 1 aims to rigorously analyse pedagogical interactions between students and teachers through projects. The framework is an expanded version of Figure 4. The activity of students (learners) as the large yellow bottom triangle intersects with the activity of teachers – such as Tech School educators – as the large blue top triangle. These large triangles representing the *personal layer* of pedagogy are divided into two smaller triangles through the overlay of the green diamond. The overlap between the large triangles creates a purple diamond shape in the centre. This diamond represents the *project* that the students are involved in as the *collective layer* of pedagogy. The green diamond surrounding it represents the *lesson layer* of pedagogy with a focus on *relational learning*. A Tech School plays a significant role in this layer as it utilises features of the *learning environment* and *authentic practices* to mediate between the project (which has been informed by industry), and student and teacher pedagogical practices (informed by education). Thus, the green diamond represents the *mediating role* of the Tech School in relating industry and education as a dialectical interaction.

As previously discussed in Section 2 of the literature review, project-based pedagogy is dialectical and multi-layered. Yet, by breaking up the different aspects of pedagogy into smaller units (shown in different colours) the actions of the students and the educators can be more clearly analysed as interrelated parts of the whole program.

These units become *cells of pedagogy* acting as relational parts of the whole program. The notion of a cell as a relational construct for development is a central aspect of Neo-Vygotskian theories such as CHAT (Engeström, 1999).

The use of coloured circles and arrows in each part of the framework represent the direction of attention by the teachers and students. A significant aspect of pedagogy involves orientating participant attention towards specific Objects and actions. This stage of the program informs the focus of the participants and promotes a certain type of *pedagogical consciousness*. Stages of the program are numbered (1-5) on the analytical framework as a guide to sequencing the pedagogical interactions in a project-based program. Tech School programs often follow this sequence, yet other sequences are possible. The sequence involves a progression of student activity between layers of pedagogy which can be described as a movement from the bottom left side (student agency) towards the centre of the framework (project layer) and out towards the bottom right side (growth of capabilities). The educators' activity is largely directed towards supporting this progression through stages with distinctive pedagogical actions depending on the stage of the program. These additional features of the framework were added after observing multiple programs in Tech Schools and secondary school projects. The relationships between educator and learner actions across program layers are now outlined as well as key terms from Analytical Framework 1.

Stage 1. Personal layer: Fostering *student agency* and building a *personal connection* between students, the educators and the program itself constitutes the first stage of project-based pedagogy. As the endpoint of personal learning is the *growth of student capabilities*, the educator *differentiates* the program based on student interest and need.

Stage 2. Lesson layer: Student activity is increasingly orientated towards the establishment of a *learning community* which is supported by the educators' activity of introducing the students to *authentic practices* related to the project and designing a suitable *learning environment*.

Stage 3. Project layer: Students now work as *team members* on their projects using *tools* supplied by the educators and developing a range of interpersonal and technical *skills*. The educators' role is varied in supporting the specific needs of students working in teams on *different projects*.

Stage 4. Lesson layer: Students have finished working on their projects and the joint focus of the educators and students is on *evaluating the projects* which may involve a presentation of student work and an *evaluation of the learning process* through personal and group reflection.

Stage 5. Personal layer: The end-point of the program and the main Object of learning is the *growth of capabilities* which are transferrable to new contexts and other projects. This may also involve students sharing what they have learned with other communities such as their home school or continuing their project after completion of the program.

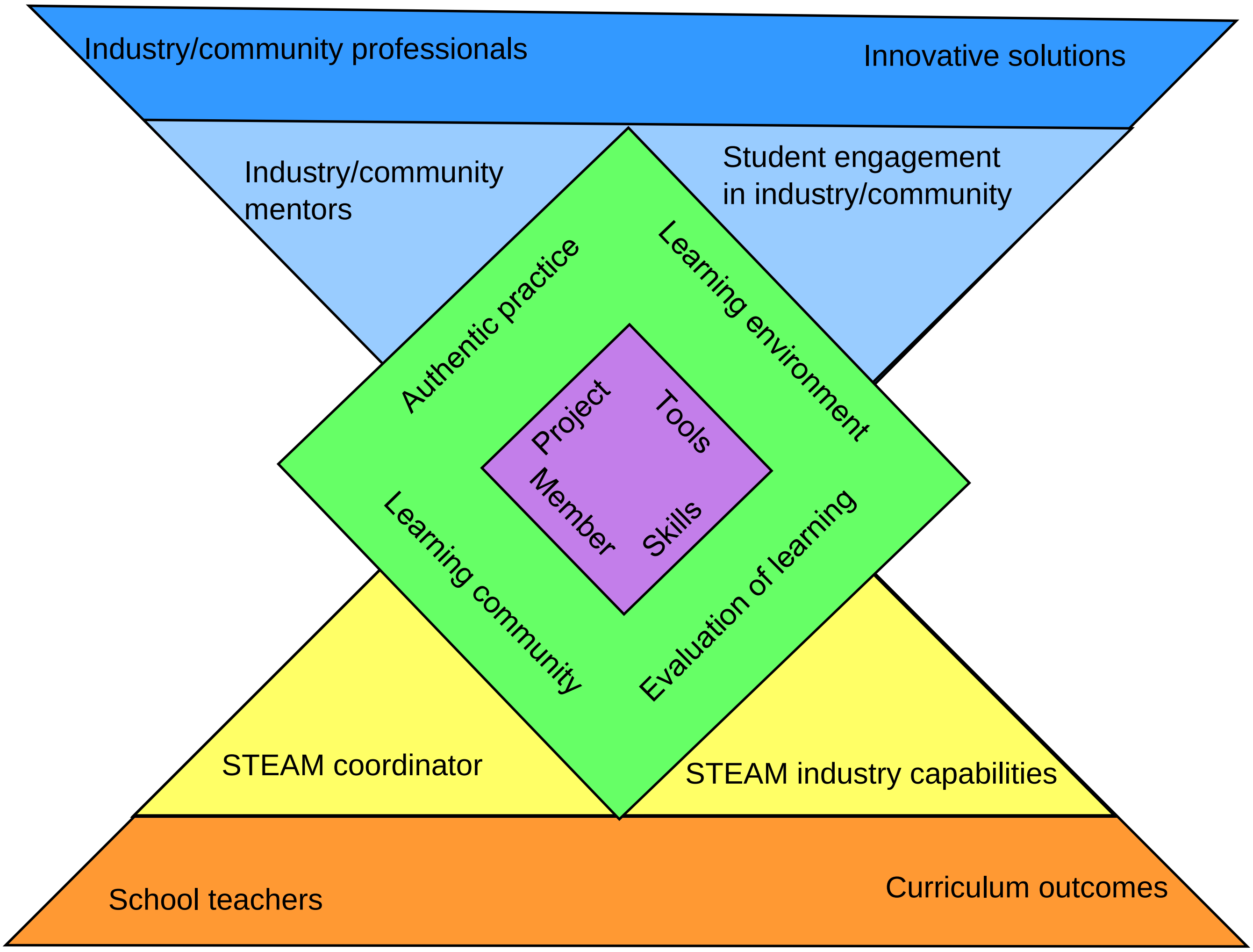
The five stages in Analytical Framework 1 are used to analyse case study 1 which compares two Tech School programs. Analysis of case study 2 (school STEAM festival) is structured using the key terms from the framework. This analysis is undertaken in Chapter 6, following the results of the case studies in Chapter 5.

Analytical Framework 2: Examining School-Industry Relations.

The role of Tech Schools in mediating school-industry partnerships was discussed in Section 2, part 4 of the literature review. In this role, Tech Schools mediate the input of industry into the co-design of STEAM programs and Tech School competitions. The literature review also highlighted how authentic partnerships between industries and schools could be facilitated through an *inter-institutional learning community* (ILC).

Analytical Framework 2 examines how Tech Schools mediate school-industry relationships through the creation of new roles in both institutions. These include the creation of *STEAM coordinator* roles in schools and the creation of *industry/community mentors*. These new roles allow for the communication of ideas across boundaries between schools and industries. The study of boundary-crossing roles between practices is central to Etienne Wenger's (1999) theory of communities of practice (CoP). A similar concept is elaborated through Anne Edwards' theory of relational agency (2005).

Both Wenger's and Edwards' theories are relevant to Tech Schools and are discussed in this chapter. Yet, they were not the starting point of the analytical frameworks which were built from Cultural-historical activity (CHAT). For this reason, similarities also exist between Analytical Framework 2 and Yrjo Engeström's third generation activity theory through a common origin: Vygotsky's theory of mediated action. A comparison between Analytical Framework 2 and Wenger's CoP, Edwards' theory of relational agency and Engeström's third generation CHAT theory is provided at the end of this chapter for a theoretical context. Framework 2 is presented in Figure 6 and its key features outlined.



Key

Organisation	Key roles
School	School teachers
	STEAM coordinator/student ambassadors
Tech School	Tech School staff
	Project developer
Industry/community organisations	Industry/community mentors
	Industry/community professionals

Figure 6. Analytical framework 2: Tech Schools mediating inter-institutional projects.

Analytical Framework 2 explained.

The use of colour coding in Analytical Framework 2 (focussed on industry engagement) is similar to Analytical Framework 1 (focussed on pedagogy). This colour coding serves a similar function in distinguishing between aspects of dialectical interaction between stakeholders. With the outer layers (dark blue and orange) representing less interaction between stakeholders and the centre of the framework (purple diamond) representing more interaction between stakeholders. The green diamond in both frameworks represents the Tech School as a *mediating organisation*, which in Analytical Framework 2 relates the activity of education and industry. In the pedagogical framework, this involved using the learning environment and authentic practices. In this inter-institutional framework, mediation is structured through an ILC which includes: Tech School educators; industry mentors and professionals; STEAM coordinators; school teachers and student ambassadors. Each of these stakeholders contribute to the design of the programs or competitions which involve student projects in the centre purple diamond.

The Objects of industry and schools are different, in that school teachers aim to cover the curriculum and industry leaders aim to design innovative solutions and products. Yet, through Tech School mediation these Objects become *dialectically entangled* as student projects are both informed by the curriculum and industry issues needing solutions. The projects themselves are not only *constituted by the Objects* of these activities, but the projects can *reorientate the Objects* of these activities. For example, projects can be a more meaningful way of teaching the curriculum by integrating the curriculum into the design thinking process and drawing on industry issues (A. Diefenthaler et al., 2017). Similarly, student projects can bring up important issues related to social equality and environmental sustainability in industry which come from the curriculum. This is why Tech Schools as mediating organisations dialectically relate industry and education as they entangle the Objects from both practices. Key features from the framework are listed below and key terms have been italicised:

- Contexts for practice (Stakeholder organisations): These sections of the framework represent *industry and community organisations* (dark blue) and *schools* (orange). These organisations have distinct Objects related to their own practices. These Objects can be orientated by the Tech School towards the Objects of the other institutions. This interaction is represented as overlapping triangles of activity between the stakeholders.

- Mediated interaction (Projects): Shown as the purple diamond, project development as mediated by Tech Schools is central to building school-industry engagement. Projects can be in the form of competitions, design challenges, in-house programs and in-school programs. These *projects* are usually co-designed with industry and community representatives. Projects are often reviewed by a program advisory board (PAB) consisting of teachers, *STEAM industry mentors* and school curriculum leaders such as *STEAM coordinators*. School teachers are sometimes involved in the initial project co-design process. Successfully designed projects allow students to develop specific *technical skills* in manipulating *tools & technologies* as well as *social skills* for *team membership and management*.
- Mediating organisation (Tech Schools): Shown as a green diamond, the Tech School mediates between stakeholders in the development and implementation of projects. Tech Schools as mediating organisations, provide a physical environment for bringing together stakeholders as well as a social network of expertise. The Tech School fosters intersubjectivity between industry and school representatives through the development of a *learning community* and *authentic practices*. Stakeholder objects are related through the *learning environment* and *evaluation of learning*. This learning practice includes the learning of the participating school students, teachers and industry mentors. Thus, the notion of learning is broadened to promote inter-institutional learning in organisations.
- Ambassadors (STEAM coordinators and industry mentors): Shown in light blue and yellow, these are emergent roles for schools and industry. In some cases, these are specified roles with job titles from organisations. In other cases, the participants from industry and schools become informal ambassadors for the projects they are involved in. *Student ambassadors* from schools are also examples of stakeholder representatives by providing a student voice in the development of projects. The ambassadors from industry and schools have a key role in fostering an inter-institutional culture which broadens existing Objects and promotes new practices in their own

organisations. This can involve tensions due to a reluctance for change in some schools and industries. For this reason, supporting ambassadors is seen as a crucial aspect of Tech School's mediation of inter-institutional activity.

Analytical Framework 2 is used to analyse case studies 3 and 4, which focus on expanding practices in schools through inter-institutional engagement and interdisciplinary projects. This analysis is undertaken in Chapter 6, following the results of the case studies in Chapter 5.

Comparison with Other Social Learning Frameworks.

Specific similarities and differences with Etienne Wenger's Communities of practice (CoP) framework, Anne Edwards' relational agency theory and Yrjo Engeström's framework of expansive learning are now presented to theoretically situate Analytical Framework 2 relative to leading social learning theories. To a lesser degree, these theories are also relevant to Analytical Framework 1 and the conceptual framework through their dialectical structure.

1. Communities of Practice (CoP).

Etienne Wenger's CoP is a conceptual framework for examining learning as part of a social network (1999). Building from Lave and Wenger's notion of situated learning (1991), CoPs are informal groupings of individuals with common experiences and competences related to their practice. Key aspects of community membership include: a sense of being involved in a joint enterprise; establishing norms for mutual participation and engagement in the group; and a shared repertoire of communal resources (Etienne Wenger, 2000). These three aspects act as interrelated dimensions of a CoP.

In studying a CoP as a social unit, Wenger highlights the importance of *boundaries* that define membership and a sense of belonging through common standards of competence and some – but not too much – diversity of experiences. Boundaries between communities create necessary tensions for growth through learning and can create new interdisciplinary communities through *overlapping practices*. Negotiating the overlap between communities can be brokered by individuals, which Wenger calls "boundary spanners" (2000, pp. 235-236). One way that different communities can be connected is through *cross-disciplinary projects* which act as "boundary objects" for promoting growth and learning in and between communities

(Etienne Wenger, 2000, p. 238). Wenger's theory has been utilised extensively in organisations which promote worker agency for innovation (Etienne Wenger & Snyder, 2000) as well as in education for fostering subcommunities of teachers within schools.

Similarities and differences.

Wenger's framework has a similar unit of analysis as Analytical Framework 2. A CoP is similar to an inter-institutional learning community (ILC) with a mediating organisation relating the activities of different members. Yet, a mediating organisation – like a Tech School – is a *designed space* with formal processes to promote cross-institutional collaboration, whereas a CoP is formed by the informal coming-together of participants. Further, a mediating organisation has a *defined purpose* which is to change practice in either one or all the participating groups, whereas a CoP may serve a purely social role. Finally, Tech School mediation has a focus on *learning* through collaboration on educational projects. For this reason, the term "inter-institutional learning community" (ILC) is used in Analytical Framework 2 rather than "Community of Practice" (CoP) to highlight the learning-focussed relationship between institutions like industry and schools (Dille & Söderlund, 2011).

Tech Schools as mediating organisations can be seen as an extension of Wenger's notion of "boundary spanners" in providing a relatively stable environment with its own boundaries of practice which extend within the practice of schools and industry. In this way, a "mediating organisation" elaborates on Wenger's theory through a formally established organisation to support an ILC involving representatives from education, industry and community.

2. Relational agency.

Anne Edwards' theory explores the professional relationships developed by practitioners from different fields. Edwards (2005) defines relational agency as "a capacity to align one's thought and actions with those of others in order to interpret problems of practice and to respond to those interpretations" (pp.169-170). Theoretically, relational agency stems from CHAT in exploring the social interactions between individuals and their joint action (Anne Edwards, 2007). Building from Vygotsky's theory of mediating artefacts such as language, Edwards considers other *people as resources*, as they share their expertise to generate knowledge across professional boundaries, collaboratively "expand the object of activity" and align their responses to solve a complex problem (Anne Edwards, 2011, p. 34). Further, relational agency is focussed on relationships between *individual practitioners* to cross boundaries between professions which is mediated by "knowing how to know who" (A. Edwards, 2005, p. 178). Her theory of "relational expertise" for inter-professional work extends her focus on common practices at the boundary between professions including: developing collaborative tools; sharing knowledge; being responsive to others; rule bending and risk taking (Anne Edwards, 2011, p. 35).

Applications of relational agency include examining teacher education to promote a greater emphasis on collaboration between teachers in responding to the specific learning needs. Relational agency has also been used for studying multi-profession practices to support the social inclusion of children involving psychologists, teachers and social workers (A. Edwards, 2005).

Similarities and differences.

Anne Edward's theory of relational agency has a common theoretical starting point to Analytical Framework 2 which is CHAT. In both cases, the agency of participants is related by their interactions using cross-disciplinary tools and practices. Edwards' notion that participants who align their practices around a common Object expand their own professional Objects, is similar to the analytical framework's focus on the dialectical relationship between industry and education stakeholders through entangled activities. Yet, Analytical Framework 2 proposes that this transformation of practice needs *to be contextualised and can be mediated* by an organisation such as a Tech School. Through the formal process of mediating the dialectic between industry and education, Tech Schools promote the creation of new roles: *industry mentors* and *STEAM coordinators*. While this can be a gradual process of changing existing roles in both practices, the purpose for developing these new roles is *to change practice in school and industry*, not just to solve a problem. In this way, Analytical Framework 2 presents mediated inter-professional activities as more than relating the agency of stakeholders, it aims at *transforming practice* through these relations.

3. Expansive learning: Third generation activity theory.

Yrjo Engeström's framework of expansive learning explores *the internal contradictions* within *activity systems* and between activity systems to generate innovative system-level solutions. Engeström describes the key features of third generation activity theory as "conceptual tools to understand dialogue, multiple perspectives, and networks of interacting activity systems" (2001, p. 135). Expansive learning is the third iteration of Cultural-historical activity theory (CHAT). The first generation of CHAT was established by Lev Vygotsky (1978) with a focus on artefacts used for a *mediated act* by an individual Subject to indirectly achieve an Object. This Subject-Object dialectic was represented as a mediated triangle of activity by Michael Cole (1996). Second generation CHAT was expanded by Alexei Leont'ev (1981) who focussed on the relationship between the individual and the system used to organise *collective activity*. Engeström's two-tier framework of mediated activity represents this relationship (Engeström, 1987, p. 78). Third generation CHAT examines the interaction between *two activity systems* through overlapping Objects of Subjects informed by the features of their systems such as community, rules and the division of labour (Engeström, 2001). Each generation of CHAT expanded the unit of analysis from (1) the mediated individual act, to (2) the mediated collective activity system, to (3) the mediated interaction between activity systems. A central theme in each reformulation is the Marxist theory of *dialectical materialism*, whereby development is driven by historical processes to overcome or synthesise contradictions through material features of a system. These material features become mediating artefacts.

Expansive learning has been used by the research driven *Boundary Crossing Laboratory*, and the *Change Laboratory* as “formative interventions” to facilitate multi-organisational system transformations (Morselli, 2019, p. 43). Notable applications of expansive learning include health care (Engeström, 2001, 2016), education environments (Engeström, 2009) and organisational learning in a variety of work environments (Virkkunen & Newnham, 2013).

Similarities and differences.

Both analytical frameworks 1 and 2 have been developed using a similar process to Yrjo Engeström's framework of expansive learning by elaborating on Vygotsky's triangle of mediated action. They have a similar emphasis on institutional-level mediation to address contradictions in and between stakeholder activities. Yet, a key difference between Engeström's framework and Analytical Framework 2 stems from the initial elaboration of Vygotsky's theory. Analytical Framework 2 presents the dialectical tension as occurring *between individuals who are engaged in a joint activity* such as a project. The interaction between individual actions is dialectically related in layers from the peripheral participation at an individual level, to an inter-subjective layer and finally a collective layer in the project. Yet, Engeström followed on Leontev's focus on the dialectical tension *between an individual and their role in a collective activity* in his formulation of a second-generation CHAT framework. Thus, for Engeström the tension is between the Object of an individual and the rules, division of labour and community in collective activity.

In the third-generation CHAT framework, Engeström has shifted the focus to the tension between the Objects of individuals as part of different activity systems which he terms “object 3”. Yet, Engeström represents this as overlapping ovals without any structure for this interaction. Analytical Framework 2 is directly focussed on this *dialectical interaction of Objects through joint projects and the role of a mediating organisation* in supporting the attainment of the ‘object 3’. Thus, Analytical Framework 2 extends Engeström’s expansive learning framework in shifting the unit of analysis to the context of mediation through a *mediating organisation*.

Summary of theoretical Comparisons.

The purpose of providing an outline of three alternative frameworks for studying social learning has been twofold. First, it demonstrated how each framework can be used complementarily to examine a specific aspect of social learning interactions. Etienne Wenger’s CoP is useful for examining the development of personal and professional identity in informal groupings of individuals with different experiences and types of expertise. Anne Edwards’ relational agency focusses on the intersubjective knowledge that emerges from aligning the Objects of different practitioners towards a common Object. Yrjo Engeström’s expansive learning focusses on the tensions between individuals and the community they work in. These inter-community tensions may impact on the development of joint Objects with individuals from different communities. Each of these frameworks *can extend the insights which emerge from using Analytical Framework 2* to examine the researched case studies. They can broaden and deepen discussion around tensions and opportunities of Tech School mediation between industry and schools through projects.

Second, Analytical Framework 2 adds a new dimension to the other frameworks, by contextualising mediation between stakeholders. In this way, the unit of analysis is a *mediating organisation*. In each of the other frameworks the new zone created by overlapping professional activities is only partly defined. In a CoP it is mostly informal, in relational agency it is based on individual actions and in expansive learning the analysis is on the interaction between stakeholders and their communities. In Analytical

Framework 2, the unit is the Tech School as a purposeful and structured organisation which is designed to mediate the interactions between stakeholders. A "mediating organisation" *as a unit of analysis opens up new potentialities for each of the theories*.

Relating the Analytical Frameworks to the Conceptual Framework.

Analytical frameworks 1 and 2 represent dialectical relationships between participants in two major activities of the Tech School. Analytical Framework 1 examines the relationship between teaching and learning in project-based pedagogies, while Analytical Framework 2 examines the relationship between schooling and industry/community as an inter-institutional activity. In the conceptual framework, these dialectical interactivities are collapsed into simpler mediating triangles with the Tech School acting as a mediating organisation between the two activities.

In the conceptual framework for the study (Figure 2), *Project-based pedagogies* and *inter-institutional relations* are concrete activities of Tech Schools which mirror more abstract activities of *educational politics* and *educational research*. In this way, Tech Schools mediate on two levels: first, the specific, immediate, concrete activities which are pedagogical and inter-institutional. Second, the broader context of activity which includes *educational research* such as critical theory, constructivist theory, Cultural-historical activity theory – and – *educational politics* which includes the STEM initiative with industrial, economic and vocational motives. While the broader relationships between politics and research underpinning the Tech School initiative have been discussed in depth in Chapter 2, the local context of pedagogy and school-industry engagement will be explored through case studies in Chapter 5. Two other local activities are explored using case studies. These are shown in the conceptual framework as (3) *interdisciplinary program design* and (4) *inter-institutional learning community (ILC)*. These Tech School mediated activities can be seen as bridges that span the local and the broad context of the Tech School initiative.

At a local level, Tech Schools support student engagement in learning at school by reorientating the *mandated curriculum* towards mediating the student-school relationship with (3) *interdisciplinary programs* (shown as the purple diamond on the left). Embedding the curriculum into meaningful projects reflects a significant impact on education by Tech Schools. It connects the *inter-institutional relations* fostered by Tech Schools (2) with the *project-based pedagogies* trialled in Tech Schools (1). Beyond supporting this transformation for local schools, using the curriculum as a mediating tool – rather than an Object or Subject of education – could have an impact on relating the political activity of the DET with research in progressive education using constructivist theory.

Similarly, at a local level Tech Schools support the development of an *inter-institutional learning community* (4) which brings together teachers and industry/community representatives. Tech Schools mediate this relationship by fostering a change to professions in education and industry. Examples of *new professions* that cross boundaries include STEAM coordinators in schools and industry mentors which require an understanding of how to foster *inter-institutional relationships* (2) and *project-based pedagogies* (1). Expanding professions in industry and education to encompass "boundary crossing roles" not only has an impact on participating schools and industries in Tech School projects; it could also impact on the political focus of education by broadening teacher training to include working with community and industry as well as furthering research into progressive models of education.

Each of these Tech School impacts are empirically researched using case studies of Tech Schools and secondary schools. These case studies are first examined using the analytical frameworks 1 and 2 in Chapter 6. Following analysis of these case studies, final discussion between the broad and local activities of Tech Schools is reserved for Chapter 7 in relating the case study analyses to the broader themes from the literature using the conceptual framework.

Chapter Conclusion

The conceptual framework for the research study emerged through the process of relating and synthesising key themes from the literature review in Chapter 2. The main themes of the review were the *political context of education* in relation to industrial and social progress, and research into progressive models of education with a focus on *constructivist theories of pedagogy*. Tech Schools were presented as a designed initiative for mediating the dialectical relationship between both aspects of education. The concept of a "mediating organisation" was developed from Cultural-historical activity theory by elaborating on Vygotsky's theory of *mediated action*. To study the dialectical relationships mediated by Tech Schools at a local level, two analytical frameworks were presented. Analytical Framework 1 is focussed on the dialectical relationship between teaching and learning in *project-based pedagogies* mediated by

Tech Schools. Analytical Framework 2 is focussed on the role of Tech Schools in mediating the dialectical *relationship between industry/community and schools* through projects and new professional roles. Analytical Framework 1 was situated within a constructivist paradigm of educational theory (outlined in the literature review). Analytical Framework 2 was situated relative to three contemporary theories of social learning. Synthesising the analytical frameworks into the conceptual framework allows for case study research at a local level to be related to the broader themes of educational politics and research. This increases the generalisability of the theory of Tech Schools as mediating organisations which could have broad impacts for education and theory. The process of generalising from specific case studies through cross-case analysis is outlined in Chapter 4.

Chapter 4: Methodology

Introduction

This chapter explains the purpose for the research including the research question, the overarching research paradigm used, the selection of case studies, the data collection and analysis methods. Sections 1and 2 justify the choice of a mixed method comparative case study design and a constructivist research paradigm based on their suitability for researching Tech Schools as a new educational initiative. In Section 3, the research design is outlined with an evaluation of the choice of case studies based on their function in answering the research questions. Brief descriptions of settings and participants are included, as well as ethical considerations. Data collection methods are detailed relative to each case study. In Section 4, primary, secondary and tertiary analysis procedures are outlined. This includes the development of analytical frameworks for standardised evaluations, triangulation and cross-case analysis as well as the integration of analyses into the conceptual framework.

The Research Problem and its Purpose

Education is slowly responding to changes in society related to technological impacts on industry and community. STEAM project-based learning is an example of a movement in education towards interdisciplinarity and making authentic connections to work outside of school (Thomas & Huffman, 2020b). Yet, secondary schools have a varied capacity for making the paradigm change from subject-based learning to project-based learning (Thomas & Huffman, 2020a). Tech Schools could play an important *mediating role* for supporting schools to develop project-based STEAM programs. This extends beyond the political function of Tech Schools as STEM centres for school excursions.

How secondary schools were embedding STEAM projects into their existing school structures, and the role of Tech Schools in this process was the central focus of this research study. This was worth investigating because the educational potential of Tech Schools to act as *positive disruptors* to the education system had not featured in government reports on Tech Schools. Based on a review of the literature, it was hypothesised that mainstream secondary schooling would *best utilise the full affordance* of the Tech School initiative by embedding interdisciplinary project-based learning within their schools. For this reason, a study on Tech Schools as "mediating organisations" for supporting secondary school STEAM integration could have implications for contemporary education research beyond the local context. An examination of *why* change to the structure of mainstream subject delivery in schools might be needed, was the first part of the research problem. *How* Tech Schools could mediate this change to secondary schooling, was the second part of the research problem. Both parts are critically examined in this thesis in terms of their interrelated political and pedagogical dimensions.

Sequence of the Research Process

2018: Most of the first year of the study was dedicated to examining literature on the political context for the Tech School initiative. This included new pedagogies, international examples of STEAM projects and schools engaged in project-based learning. This extended review of the literature was due to the main Tech School to be studied being under construction throughout the first year. Attendance at curriculum planning meetings with school teachers, industry representatives, and Tech School administration provided a context for the development of the Tech School. Pilot programs run in a temporary facility in the last two months of the year brought to light potential issues to be researched.

2019: A year-long case study of one Tech School, a case study of a local secondary school STEAM festival, and a case study of industry collaborations supported a contextual understanding of the Tech School initiative. 3-day observations of programs run in two Tech Schools using standardised success criteria enabled pedagogical insights to be transferred across sites for increased generalisability.

2020: An in-depth case study was conducted of a secondary school STEM unit run over a term including interviews with teachers and interdisciplinary school leaders. Only interviews from the case study were included in the thesis due to the interruption of the unit by the COVID-19 pandemic. Final data analysis of case study results was undertaken and the thesis chapters were drafted.

April 2021: The research project was completed and the thesis submitted.

Outline of the Study Populations

Over the course of this study, diverse stakeholders relevant to the Tech School programs were researched to provide a multi-dimensional understanding of the initiative. Populations were selected based on the requirements of the case studies to highlight different activities which Tech Schools were conducting. A brief outline of the populations researched relevant to each case study is presented. Description of the case studies is provided in Section 3 of this chapter. A comprehensive overview of the case study and participants is provided in the Results chapter.

Case study populations.

Case study 1: Programs run in two separate Tech Schools in regional Victoria were compared, with similar populations studied for each program. This included the Tech School educators delivering the programs, the visiting teachers from the local secondary schools and their students from Year levels 9-10.

Case study 2: A four-day STEAM festival run in a regional secondary school provided an opportunity to observe, to conduct a survey and interview students from Year levels 7-10. Interviews with teachers who taught different subjects provided a range of perspectives on the benefits and challenges of the STEAM festival.

Case study 3: Two industry related activities coordinated by a single Tech School were selected to focus on the relationship between schools and industries involved in STEAM projects. The local industry representatives, students and teacher from a single school, and the Tech School staff participating in the projects were from the same regional city.

Case study 4: Interviews conducted across the entire study were analysed to examine the benefits and challenges of integrating STEAM projects into secondary schools. The populations selected for this case study included: students; teachers; school leaders; industry representatives and Tech School directors, program managers and educators. The triangulation of interview comments organised into themes provided a multi-dimensional perspective of integrating interdisciplinary projects into schools.

This outline of the study populations serves to contextualise the study. It emphasises the interconnections between diverse stakeholders in projects mediated by Tech Schools, explored through a comparative case study methodology.

Constructivism, Mixed Methods and a Comparative Case Study Methodology

Mediation from a Constructivist Perspective.

Constructivism was a theoretically fertile methodological paradigm for examining the tensions within the Tech School initiative. To study Tech Schools as a *political-educational construct*, a "mixed methods" approach to collecting data was used and dialectical frameworks were designed for data analysis. The analytical frameworks and the conceptual framework allowed theoretical and practical research to be related (Teddlie & Tashakkori, 2009). For example, integrating cross-case analyses of case studies within the conceptual framework enabled an exploration of the different ways that Tech Schools might *mediate* between community, industry and schools as "mediating organisations". Constructivism provided an ideal theoretical perspective for examining a multi-dimensional construct such as "mediation" from two angles:

- *Social mediation* (Subject-orientated mediation) between the Tech School educators, school teachers, students and industry representatives.
- *Paradigmatic mediation* (Object-orientated mediation) in the form of policies and documents such as STEAM curriculum; tools and resources including technologies; events such as professional learning workshops; codesign sessions and pedagogical processes for project-based learning such as the design thinking process.

These two angles for examining Tech School mediation reflect the dialectic between subjective and objective means of constructing knowledge (J. Bruner, 1986). This Subject-Object dialectic informed the analysis of mixed data in three stages:

- Primary analysis: through the triangulation of interviews, surveys and observations
- Secondary analysis: through the utilisation of analytical frameworks on pedagogy and institutional engagement
- Tertiary analysis: using the conceptual framework to synthesise key insights gained from primary and secondary analysis and relating these insights to the literature

Constructivism lent itself to the study of Tech Schools as organisations mediating between individual stakeholders as well as the institutional context for that mediation. This is because a "mediating organisation" as an *institutional construct* could be studied as a *conceptual construct* which connected to constructivist theories of education and research. The conceptual framework embodies this transformation between conceptual and institutional constructs.

Mediation contextualised through constructivist analysis of case studies.

The many forms of social and paradigmatic mediation which Tech Schools undertake represent different *situated actions* between individuals in settings such as a Tech School, secondary schools or online over a set period of time. Each of these interactions is a "bounded unit" which is suited to a case study methodology (R. K. Yin, 2015). Each case study represents a different type of mediation provided by the Tech School which were then organised in levels of impact on the school system. Cross-case analysis utilised analytical frameworks derived from CHAT and constructivist theories from the literature. In this way empirical data from specific case studies were related to general theories of education as a two-part process.

The methodological relationship between the comparative case study and constructivist theory is examined in two sections: first, an overview and justification for the choice of a comparative case study methodology is provided. This is followed by a description of how each case study addressed the research question and sub-questions. The second part of the methodology – constructivism – summarises the overarching theoretical perspective of the research study. The chapter then outlines the research-design of the study, methods of collecting data and the process of analysing key themes from each case using analytical frameworks.

Section 1: Choice of a Comparative Case Study Methodology

A comparative case study methodology enabled an ill-defined, loosely bounded interaction – "mediation" – between Tech Schools and secondary schools to be empirically studied. The aim was to develop a *generalisable concept* of a "mediating organisation" through an investigation of the local and broad contexts that Tech Schools operated within. Studying Tech Schools as *mediating organisations* required a reconsideration of case study methodology because the purpose of the case studies was to empirically *verify through induction*, general themes which were *deduced from the literature* and organised in a conceptual framework.

Cross-case analysis for conceptual generalisation does not seem to match the *common interpretation* of case studies provided by R. K. Yin (2015, p. 194), where a case study is an "up-close and in-depth inquiry into a specific, complex, and real-world phenomenon (the case)." Yin explains that case study methodology, with roots in sociological, psychological and anthropological research, is focussed on the *real-world specifics* of the context of the study. Yet, the notion of a "context" can extend the boundaries of situated space and time, and still be a case study. For example, the *political context* of the Tech School initiative is a *generalisable concept* which dictates the *structures of mediation* by Tech Schools as organisations. These structures shape the *local, situated interactions* in Tech Schools. Thus, the *structures of a mediating organisation* can be examined through case studies and abstracted as emergent themes. According to Yin and Davis this reflects a relationship between "the phenomenon of interest and the surrounding events as its context" (2007, p. 78).

Reconciling the local and general *organisational context* for mediation was crucial to understanding Tech Schools as "mediating organisations". Yet, generalising from separate case studies without compromising the *internal validity* of the case study methodology required clarity of purpose and method (R. K. Yin, 2015). This clarity was achieved through the design of an overarching conceptual framework linked to theory, which was translated into analytic frameworks used to explore themes emerging from case study data. The organisation of Tech School mediating activities and the structure of the analytical frameworks were *conceptually aligned*, allowing for the process of: (1) case study data triangulation; (2) comparative case study analysis; (3) thematic synthesis and (4) conceptually framing the themes to relate to the literature and build theory.

Conceptually, Tech Schools as "mediating organisations" were contextualised in layers from local contexts (specific cases such as a program, a workshop or a festival) to larger contexts such as the political context of promoting student engagement in STEAM subjects to meet a changing industrial economy. These two contexts – *local context* and *broad context* – were interrelated, with the actions and beliefs of the participants in the case studies reflecting particular ideologies examined in the literature review. To relate both contexts, the research moved through phases involving deduction and induction.

Deduction: The broad political themes were identified through a study of the literature on changes to education in response to the technologization of industry and business. The political role of Tech Schools in facilitating the aims of the STEM education strategy were examined in national reports and through an informal interview with the Tech School division of the Victorian Department of Education and Training (DET). Potential impacts which Tech Schools could have on education were outlined in an early version of the conceptual framework. This informed the design of case studies which seemed to embody tensions and opportunities noted in the literature review. In addition, informal observations of the design of Tech School programs, their implementation and informal discussions with key stakeholders involved in the Tech School initiative contributed to the research design. This structured approach to the case study design was based on Yin's emphasis on "objectivity, validity and generalizability" which according to Yazan reflect a *positivist epistemological leaning* (2015, p. 136). Once a plan for researching the different aspects of the Tech School was developed, the research moved into an inductive phase as the findings from each case informed the selection of the next case.

Induction: The empirical process of researching Tech Schools as mediating organisations was to reveal the broader generalisable historical-political force enacted on education *from* the interaction between the Tech School and the participating secondary school students, teachers and industry representatives studied in each case. Yazan considers this to be representative of Stake and Merriam's constructivist approach to case studies which develop through "progressive focussing" (2015, p. 141). Induction proceeded from the local context (selected case studies) to the broader context (historical-political agendas) which was the reverse of the deductive application of the conceptual framework to design the case studies. This relationship is shown in Table 5.

Table 5
Case Study Design of Tech Schools Mediating Between Contexts

Context studied	**Research focus**	**Research method**				**Reasoning method**	
Broad educational context	Sociological theories of education	Literature & theory ↔ Conceptual framework				Deduction ↓	Induction ↑
Mediating context	Tech School as a mediating organisation between broad and local context	Analytical Framework 1		Analytical Framework 2			
Local institutional context	Examples of Tech School mediation with schools and industries	Case study 1	Case study 2	Case study 3	Case study 4		

This case study design demonstrates that Yin's deductive and Stake and Miriam's inductive approaches to case study can be integrated as stages of research, which equally applies to constructivist epistemologies. This is another example of the compatibility of case study and constructivism as a methodology.

Sociological Influences on the Local Case Studies.

Studying the Tech School initiative using a comparative case study methodology enabled analysis and synthesis through the use of deduction and induction as an iterative process. This reflected the interaction between observable local activities (such as teachers' pedagogical actions) and sociological influences (such as the focus on industry solutions in projects). Tech School organisational structures such as learning programs, PL, school-industry co-design were enacted as specific and situated *social interactions*. Yet, Tech Schools were designed with a political motive, which required their organisational structures to be studied from a *sociological perspective*.

Relating the specific case studies to the broader context of education promoted insights into sociological theories. For example, Tech Schools have emerged from a *functionalist paradigm* of education to support schools as part of a larger social organism (Durkheim, 1956). Functionally, Tech Schools support the expansion of the STEM system in mainstream education which is needed to maintain economic growth of Australian business. Yet, this functionalist theory lacks a *critical perspective*, as it allows little autonomy for the individual acting in local contexts such as schools, to shape their own development or to change the system (Kincheloe, 2005). For this reason*, critical constructivist theories* were better suited to researching how Tech Schools mediate between government policies and the pedagogical practices of school teachers.

Neo-Marxist and critical theorists such as Paulo Freire (1996), Maxine Greene (1978), Ivan Illich (1972/2002) and Henry Giroux (2001) demonstrated that education is inherently *a contradiction* between the autonomy and agency of the individual and the social role that education prepares them for. Further, what appears *natural* to education such as pedagogy and curriculum are *political constructions*. These theorists argued for a “de-reification” of schooling through a new sociology of education (Sarup, 1978, p. 52). Exploring this tension was a central theme of this research study. Tech Schools have been designed to *reify* a political agenda (STEM engagement), yet, Tech Schools have a role in supporting schools to develop their own programs which involves *de-reification* of institutional structures to meet diverse agendas.

From a *theoretical perspective*, the research study explored how the dialectical tension between top-down political motives for education – and – the development of greater autonomy and agency by teachers and students could be synthesised through a mediating organisation such as a Tech School. From a *pragmatic perspective*, the study questioned whether social and political forces driving the Tech School initiative, could be directed to meet the needs of individual learners, teachers and schools by *channelling* resources, research and policy change (Serdyukov, 2017). A comparative case study methodology was used to map out areas in the education landscape which could be redesigned through the Tech School initiative. The four case studies researched, served as a survey of dominant features in this education landscape: pedagogy, programming, community and policy.

Studying a Mediating Organisation through Case Studies.

Two reasons are provided for using case studies to examine the concept of a Tech School as a mediating organisation and to evaluate its enactment. These address Yin’s criteria of a case study as “an up-close and in-depth inquiry into a specific, complex, and real-world phenomenon” (2015, p. 194).

1. *Specific, complex and real world*: through an in-depth study of the Tech School and local schools, the notion of a mediating organisation emerged as a real need to address complex impediments to project-based programming in schools such as timetabling, curriculum, leadership and subject silos. Addressing these issues defined the context for Tech School mediation as real-world impacts on schools, which were explored in the case studies. These issues reflected both a concrete reality for the participants in context of their practice and theoretical issues explored in the literature on constructivist education.
2. *Up-close & in-depth*: the activity of mediating between stakeholders such as industry and schools, was actualised in specific situated events such as co-design workshops, competitions, festivals and professional development sessions which could be observed up-close as case studies. Examining how Tech School educators, teachers, students and industry representatives interacted in these different events involved studying people engaged in actual practices, not as abstractions. Case studies provided in-depth examples of educational mediation as a practice enacted through the relationships between stakeholders.

Generalising case studies through analysis and synthesis.

As previously noted, the case study genre tends towards in-depth examinations of a specific phenomenon rather than generalisation (Robert. E Stake, 1995). Yet, comparative case studies can be utilised to study complex, multi-dimensional education reforms such as the Tech School initiative, if the case studies are organised within a "logic model" which in this study is the conceptual framework and the analytical frameworks (R. Yin & Davis, 2007, p. 81). The specific method of deriving generalised findings from specific cases is described by Yin as "analytical generalization" (2013, p. 325). According to Yin (2015) generalisation can be achieved at a "conceptual higher level" than the individual cases through abstraction, where underlying principles are not just common to similar cases, but also to different types of cases (p. 199). Through the use of analytical frameworks, the case studies were comparatively analysed to understand the emergent theme of a *mediating organisation* which connected them. The analyses were then related to theory for generalisation using the conceptual framework. The issue of maintaining internal and external validity in relation to the case study design will now be addressed, followed by the use of mixed methods.

Testing the Comparative Case Study Design.

Comparative case study was an ideal means of studying mediated interactions which occurred in specific contexts of time and place, yet reflected a broader context of history and politics. The validity of the study design was tested according to four design tests in case study research by Riege (2003): construct validity, internal validity, external validity and reliability. As these tests have significant overlaps, reliability is included in internal validity and construct validity is included in external validity.

(i) Internal validity.

The internal validity of the study was focussed on the relationship between the Tech Schools and the *local context of schools*. Mixed methods data collection and triangulation for primary data analysis provided within-case validity (Flick, 2018). The issue of whether interview comments from different participants, surveys and observations provided reliable evaluations of "quality" in pedagogy and program design was identified in the analysis of early *pilot studies*. Based on this insight, the reliability of methods and findings was increased by designing rigorous data collection and analysis tools allowing for triangulation and pattern matching (R. K. Yin, 2013). This included developing *standard evaluation criteria* for Tech School programs and pedagogies derived from synthesising constructivist education theory. Further, analytical frameworks allowed for *cross-case analysis* of themes such as quality of pedagogy across settings such as Tech Schools and secondary schools (Miles & Valsiner, 1994). By using the analytical frameworks to triangulate thick and rich qualitative data – which captured the participants' subjective context-specific experiences – with a standardised evaluation of programs, the credibility of the findings was increased.

(ii) External validity.

One of the biggest challenges of case study research is extending "from issues of validity to issues of generalization" (R. K. Yin, 2013, p. 325). The use of the conceptual framework was central to making "analytical generalisations" which could be *applied to other education contexts* (Riege, 2003, p. 81). One of the generalisations was that the construct of Tech Schools as "mediating organisations" was relevant to contemporary education theory and representative of the participants' perspectives of Tech Schools. The *theoretical validity* of the construct of "Tech Schools as mediating organisations" was first tested against literature on institutions which support/mediate/broker project-based learning, as well as CHAT theories of mediation (refer to Chapter 2). The *empirical validity* of the construct was tested against the perspectives of diverse participants interviewed such as teachers, students, Tech School directors and educators which emerged through *thematic analysis* of interview transcripts.

Building the study's external validity was crucial to relating the case study findings to the general themes in the broader context of educational reform (R. Yin & Davis, 2007). This was achieved through the use of the conceptual framework to synthesise the different organisational activities of Tech Schools into one construct, thereby achieving "coherence between empirical observations and conceptual conclusions" (Leshem & Trafford, 2007, p. 101). This allowed the construct of a *mediating organisation* to be integrated into the landscape of educational politics, practice and theory (Wenger-Trayner & Wenger-Trayner, 2014). In this way, Yin's (2013) criteria for validity and generalisation were met through a two-part process involving: *analytical frameworks in stage 1* (local-context mediation) and then embedding the analytical frameworks into the main *conceptual framework in stage 2* (broad-context mediation).

Mixed methods for data collection.

Mixed methods research lent itself to the study of Tech Schools as an emerging phenomenon in education. Due to the recentness of the Tech School initiative, there was no existing literature on Victorian Tech Schools as a field of inquiry, although literature on similar initiatives provided some context. This created a need and an opportunity for an overview study of Victorian Tech Schools as a relationship between different dimensions of education. Interviews with teachers, students, Tech School educators and directors as well as industry representatives allowed for diversity of perspectives from key stakeholders, which provided a *rich qualitative dimension* to case study research on Tech Schools (Merriam, 1998). Yet, it did not capture the political context that Tech Schools were operating within. This required a review of public reports and policy documents supporting the initiative as well as an examination of how data was being collected by the Department of Education, such as satisfaction surveys. This provided *a political dimension* to understanding Tech Schools. Finally, a need arose for utilising a standard measure of project-based pedagogy and institutional engagement to evaluate the impact that Tech Schools were having on education. The development of evaluative frameworks addressed the *pedagogical dimension* of Tech Schools as well as their impact on school structures and systems.

In this way, a mixed methods approach to collecting and analysing data addressed the *multi-dimensionality* of Tech Schools as mediating organisations. It fit with the use of case studies as a methodology and constructivism as a research paradigm (Bazeley, 2018). The research design drew upon the epistemological relationship between constructivism, case study and mixed methods to establish methodological congruence between the purpose for the study, the methods of research and the conceptual frame of analysis (Creswell, 2015). The specific methods used for data collection and the analysis are outlined later in this chapter.

The role of quantitative data.

The mixed methods study primarily used qualitative data. This does not discount, the use of quantitative data in case studies 1 and 2. The purpose for collecting quantitative data for these case studies was based on two reasons. First, the use of student surveys provided a snapshot of the students' perceptions of programs run in the Tech Schools and the school STEAM festival. The student surveys were used for evaluations of six Tech School programs, from which two have been presented. This quantitative survey data enabled broad themes related to student engagement and learning to be identified. This served as an indicator of areas to be further investigated using qualitative methods such as interviews and observations, which is typical of a sequential explanatory design (Bazeley, 2018).

Second, the survey data supported data triangulation with the standardised observation framework and participant interviews for "coherent and cohesive analysis of the data gathered" (Kervin et al., 2016, p. 77). *Consistent results* from data collected using the three methods validated the conclusions reached, while *inconsistent results* highlighted issues to be explored further. Based on these two reasons, quantitative data served as an indicator of key research focus areas and as a contributor to robust triangulation of data.

Justification for not using more quantitative data.

The iterative process of developing the study methodology consisted of a gradual shift from quantitative to qualitative methods. The starting point for data analysis was the use of one Tech School's existing data from student surveys across all programs over six months. While this data provided a large sample of student responses and a broad indication of student engagement, it *did not provide context* for the responses to support a meaningful evaluation of pedagogy and program design. To comprehensively evaluate the STEAM programs required a mix of methods, as well as perspectives from a range of participants. For this reason, student surveys became one part of the mixed method design of case studies 1 and 2. Quantitative data did not suit case study 3, which focussed on partnerships between industry and schools. The sample size of students and industry representatives was too small for meaningful statistical analysis (Cresswell, 2015). Further, the theme of mediated partnerships between schools and industry was suited to qualitative data collection through interviews with the stakeholders involved. Finally, case study 4 explored the issue of project integration in schools, predominantly from the perspective of teachers and Tech School educators. These issues were identified through thematic analysis of interview transcripts, as educators were asked to describe the benefits and challenges of interdisciplinary projects in schools. The themes which emerged, serve as a foundation for broader research which could benefit from quantitative data collection and statistical analysis.

Research Questions and How They Were Addressed.

The research questions and the research design reciprocally developed through an iterative cycle. This is an inherent quality of multiple case study analysis, as new insights, themes and assertions orientate the research process towards a more refined examination of each case (Robert E. Stake, 2006). The research study started with an in-depth case study of one single Tech School. It then progressed to examining the Tech School's relationship with local secondary schools as separate case studies. This initial deep-dive into one Tech School informed the central research question.

How can Tech Schools as mediating organisations promote student, teacher and school engagement in authentic STEAM projects?

The notion of a "mediating organisation" emerged from analysing mixed data and theoretically framing the multifaceted nature of a Tech School in its different roles. These included program delivery to schools, program development with industry and community, professional learning for teachers, and its function as an experimental space for developing new pedagogies related to technology and project-based learning. Refer to the conceptual framework in Chapter 3 for a representation of the multifaceted role of Tech Schools as mediating organisations. Tech School support for school teachers' development of capabilities – not just their students' development – broadened the focus of the research through case studies in schools. *Authenticity* became a key theme regarding Tech School projects which was explored through case studies on the role of industry in program design and industry-inspired competitions.

Research sub-questions.

The following research sub-questions were addressed through case studies included in this thesis.

1. *How do Tech School programs and pedagogies promote student engagement and growth of capabilities in STEAM?*

After a pilot study of four 3-day programs involving observations, interviews and surveys, the *evaluation of student growth* of STEAM industry capabilities as well the *authenticity of the projects* emerged as key themes for case studies.

To answer research sub-question 1, a cross-site evaluation of two Tech School 3-day programs, allowed for insights into pedagogy and program design to be compared (case study 1). A comparison of 3-day programs across five Tech Schools was initially planned. Unfortunately, due to national health recommendations to reduce the spread of a contagious virus (COVID-19), Tech School visits by schools were suspended. This case study was then scaled back to the comparison of the main Tech School site and one other Tech School where data had been collected prior to COVID-19. Further research was undertaken with one of these Tech Schools to embed the Victorian Curriculum into Tech School programs which allowed for the development of assessment rubrics for school teachers (refer to Appendix F).

2. *How do Tech Schools support the development of new teacher pedagogies related to planning, teaching and evaluating STEAM projects?*

The initial approach to answering this research question was observing Tech School PL workshops run for school teachers. These workshops *did not* provide insights on developing teacher practice in schools as they were largely a delivery of techniques in technology and design thinking. A case study on a secondary school STEAM festival provided a clearer picture of how Tech School professional learning was applied by teachers in a school context. Case study 2 revealed that the teachers effectively translated an industry-inspired Tech School program into a secondary school program through the use of the design thinking process. While the festival projects were engaging for students, the secondary school was limited in its capacity for connecting the program to the curriculum and making authentic connections with local industry.

3. *How do Tech Schools mediate the relationship between schools, industry and community?*

The findings from case study 2 led to a new case study examining how a Tech School co-designs programs with industry for authenticity. This was combined with a study on how a Tech School-industry competition was run in a secondary school for increased student agency and engagement (case study 3). The structured approach to co-designing programs and competitions with industry provided an effective model which could be adopted by schools. Yet, it also demonstrated limitations in the impact that Tech Schools have on supporting schools, without changing existing school structures related to timetabling, pedagogy and assessment.

4. *What are the affordances and constraints of embedding the Tech School model of project-based STEAM learning in secondary schools?*

Interviews with students, teachers, interdisciplinary school leaders, industry representatives, Tech School staff and directors provided critical insights on the benefits, limitations and challenges of running interdisciplinary projects in schools (case study 4). This informed the recommendation for Tech Schools to deepen their impact on education by advocating for structural changes to schooling in Chapter 7.

The answers to these research sub-questions are included in Chapter 7, following cross-case analysis in Chapter 6. These answers were synthesised into the conceptual framework to answer the main research question and to build on constructivist theories of education.

Section 2: Constructivism as an Overarching Paradigm

Constructivism is the predominant *research paradigm* for this research study. This includes the methodology, the analysis of data such as mixed-method triangulation and the concept of dialecticism in the design of the conceptual and analytical frameworks. Constructivism is also considered in this study as the most suitable *education paradigm* for understanding new pedagogies and the design of STEAM projects in schools and Tech Schools through an emphasis on active inquiry, design and knowledge construction (K. Gross & Gross, 2016). The use of constructivist theory as a research paradigm and education paradigm is outlined below as well as the relationship between both aspects.

Constructivism as a Research Paradigm.

Constructivism stems from the epistemological problem of determining the relationship between objective and subjective representations of reality (Riegler, 2011). Whether the reality that humans experience is a true reflection of the physical world, a psychological construction or a combination of both, is an ontological question which underpins much of Western philosophy (Grayling, 2019). How knowledge is constructed personally and socially is central to the epistemological paradigm of constructivism with regards to education (Kitchener, 1986). Thus, constructivism as a research paradigm in education reflects the multi-dimensional relationship between experienced reality (ontology) and knowledge creation (epistemology). Whether one adopts a biological explanation for the developing mind (Jean Piaget, 1952), or places emphasis on the internalisation of social signs (L. Vygotsky, 1978), constructivists regard *reality as an interaction between mind and world*. From a research perspective this means that one cannot study reality devoid of human interpretation which is *personal and social*, yet also refers to experiences with the *physical world*. In this way, constructivism promotes a non-dualistic view of knowledge, whereby mind and world are *dialectically interrelated through culture* (Bakhurst, 1995; Cole, 1996).

For this reason, this constructivist research study included the collection and analysis of data which captured *subjective interpretations* of reality such as interviews with multiple participants, as well as tools to establish some *objective measure* of what was being studied such as standard criteria for comparative evaluations across cases. In this study, the analytical process of triangulating subjective and objective data to validly interpret the situation is an example of *constructivism applied as a research paradigm* (Y. S. Lincoln, 2013). It reflected tensions between subjective and objective evaluations of "quality education" which informed the design of analytical frameworks to synthesise different forms of data. Finally, constructivism provided an "overriding theoretical position" to integrate data collected from mixed-methods (Bazeley, 2018, p. 17).

Evaluating quality: A subjective-objective dialectical construct.

One might regard the research aim of *objective constructivist evaluations* as a contradiction because constructivism can be interpreted as a relativistic explanation of reality based on non-generalisable psychological concepts (E. v. Glasersfeld, 2013; C.-J. G. Lee, 2012). Yet, this research study adopts a dialectical approach to examining educational *constructs* – such as curriculum, pedagogy, and school policies regarding subjects and timetables. These constructs are not entirely Subject-dependent, nor are they only objects in the physical sense. As constructed Objects they derive from human intentions and behaviours, yet they are also reified – either as physical objects such as technology (Papert, 1993), social objects such as language (L. Vygotsky, 1978) or conceptual objects such as schemes (J Piaget, 1970). Often, educational constructs are a mix of all three in the form of bureaucratic structures such as codes and roles organised into hierarchies (Bernstein, 1973; Weber, 1983). Through the use of instruments for measure and theory for interpretation, these structures can be evaluated with some degree of objectivity, which is the basis of education as a social science.

As a predominantly qualitative constructivist study, research objectivity was established through *theory for critical explanation* rather than *scientific testing for refutation* (J. Bruner, 1986; Marcuse, 1964). The utilisation of theory for objectivity has been a consistent methodological approach across the social sciences. Examples include the instrumental method in psychology (L. S. Vygotsky, 1981), socioeconomics through historical materialism (Marx, 1847/2018), pragmatism in philosophy (Dewey, 1960) and critical pedagogy in education (Freire, 1996). The work of these theorists served as a guide to developing a constructivist methodology to study the Tech School initiative. The work of Paulo Freire (1985) was particularly valuable in considering Tech Schools as a dialectical construct between politics and pedagogies.

Education is a dialectical construction because the notion of *quality* cannot be relative to the individual beliefs of each participant, nor should it contradict the beliefs of participants such as teachers and students. As a philosophical construct, *quality in education* is part of Popper's objective "World 3", involving abstraction from human experiences by using *theory* to achieve objectivity through epistemological standards (1979, p. 144). The curriculum; timetabling; and the multiple instruments and resources for teaching, assessing and reporting are constructions of "objectified human needs and intentions", which are then used as "primary", "secondary" and "tertiary" artefacts to structure human behaviour and development (Wartofsky, 1979, pp. 200-201). These constructed objects can be evaluated according to standards and principles of education, which are generalisable, even though contexts of practice can vary from setting to setting. Theory provided the generalisable standards for evaluating quality pedagogies and programs which enabled cross-case analysis.

The system of education, like law and medicine is a reified institutional construction requiring a high degree of internal consistency to fairly accommodate the diverse and highly specific needs of the Subjects it serves (Carr, 2003). To argue that such institutional systems need any change requires eliciting contradictions between the *principles* that govern the system, and their *capacity* to democratically serve their Subjects in multiple and diverse cases (Freire, 1994). Determining how Tech Schools – as organisations which mediate between system and Subject – could act as a political catalyst for re-constructing schooling through alternative principles of education was the overarching aim of the research study.

Constructivist theory informed the methodology to address this research aim. It provided a means to unravel the Subject-Object dialectic at an institutional level and at an individual level. This was possible because *theory* was common to both the principles of the system of education as a reality through *policy,* and the reality of the individual subjects that act within or against that system through their *beliefs*. In this way, constructivism revealed how *education is a multilayered dialectic between people's beliefs and institutional policies*.

Theory mediates the transition from lived experience to research methods.

The use of theory to adapt a paradigm such as constructivism from epistemology to a methodology is supported in research literature by Denzin and Lincoln (2013), Y. S. Lincoln (2013) and Crotty (1998). Creswell (2018) sees the situatedness of theory in the research process as one of the deciding factors in qualitative methodologies. According to Charmaz (2017) qualitative methodologies such as grounded theory, have roots in pragmatic constructivist philosophy. Yet, unlike Charmaz's "constructivist grounded theory for critical inquiry" (2017, p. 34), where theory emerges inductively from the data, this case study used theory – derived from literature – as an orientating device for data collection and analysis through a conceptual framework (Anfara & Mertz, 2015). In this way, *theory served a deductive rather than inductive purpose* for constructing knowledge.

This constructivist study does not discount the multiple realities of subjects as part of a "social constructionist" paradigm (C.-J. G. Lee, 2012). Yet, it does explore the *underlying structures* which help to situate these realities and examine their interrelations as part of a larger socio-political structure. Further, it attempts to eliminate the subjectivism of some social constructionist research which can be relativistic and self-referential, in not arguing from a fixed position (Hacking, 1999).

Project-Based Learning: Constructivism as an Education Paradigm.

Education is a human construct. While other animals may learn by imitation, they do not have systems of education (Cole, 1996). Further, the reality of what constitutes *quality education* is a value judgement based on social and cultural norms. It is "normative", not an inherent property of the world (Carr, 2003, pp. 217-218). In preparing students for the predicted needs of our society, many initiatives in education such as STEM (Educational Council, 2015), or even the national or state curriculum (Brady, 2014) are expressions of what education *ought* to be for. The curriculum, pedagogy, infrastructure, assessment, technology and timetabling in schools are based on what meets the social and societal *expectations of politicians and educators* at a certain stage in history which need ongoing critique and revision (Dewey, 1916/2010). In this light, a seemingly straightforward education comment such as "The curriculum is a statement of the purpose of schooling" by the Victorian Curriculum and Assessment Authority is an *expression of a political ideology* (2015, p. 3).

Throughout this thesis, when constructivist theory is discussed in relation to the researched cases it is specifically referring to *interdisciplinary project-based learning.* Interdisciplinary projects enable constructivism to take on a concrete form as knowledge is constructed through an iterative process of design, rather than repeating a formula (A Diefenthaler, L Moorhead, S Speicher, C Bear, & D Cerminaro, 2017; Huijser et al., 2015). This reflects the inter-institutional project model being undertaken between industries and community groups in the 4IR (Dille & Söderlund, 2011). From this constructivist-project perspective, a number of taken-for-granted aspects of mainstream education such as pedagogy and curriculum are critiqued as lacking an authentic connection to work and learning outside the school walls (Zhao, 2012b).

Tech Schools as constructivist education institutions.

Tech Schools were an ideal environment for studying constructivist pedagogies because they operated within a different paradigm of education. Without the constraints of timetabling, curriculum and assessment, Tech Schools could fully explore the pedagogical affordances of STEAM project-based learning. Pedagogically, Tech School programs sat within a *social-constructivist* paradigm where learning involves student and educator collaboration, as part of a community of problem-solvers (Jerome

S. Bruner, 1977; Lave & Wenger, 1991; Pieratt, 2010; L. Vygotsky, 1978). Philosophically, the design of programs which authentically replicated the social and technical practices of industry projects suggested a revival of Dewey's *pragmatic progressive* education (Wraga, 2019). This warranted a *critical-constructivist* perspective of the purpose of Tech Schools (Giroux, 2001). In this way, Tech Schools represented a departure from the standard education model of curriculum-orientated subject silos towards implementing interdisciplinary STEAM programs, relevant to technology-driven industries (Lucas et al., 2013). This created opportunities to rethink how quality of pedagogy and program design could be evaluated within this *social-critical-constructivist* paradigm of education.

Evaluating project-based learning using a constructivist methodology.

Evaluating constructivist project-based programs and pedagogies that did not fit the curriculum-driven school system required *new criteria of success* based on constructivist theory (refer to success criteria at the end of this chapter). While student mastery of curriculum content was important, it was only one aspect of evaluating pedagogy amongst other aspects such as student agency, building personal connections and engaging in authentic world issues. This emphasised the validity of the students' personal world-knowledge which did not always fit within the boundaries of formalised knowledge from the curriculum. Relating *personally, socially and collectively constructed knowledge* with the *formal structure of curriculum content* became a dominant theme of the research study.

Developing frameworks and evaluation criteria for Tech School STEAM projects was central to the research study's constructivist methodology. These tools contribute to promoting project-based learning in schools by overcoming criticisms of constructivism such as relativism of knowledge (Solomon, 1994) and poor integration of curriculum content into the project design (Kanter, 2010).

Finally, while developing a method for evaluating constructivist education was essential for conducting the research study, it also revealed a broader need for research, resources and training in constructivist project-based learning as an alternative to a standardised education system structured into subject silos and curriculum levels (Lucas et al., 2013; Wagner & Dintersmith, 2015; Zhao, 2013).

Section 3: Research Design

This research project used a comparative case study methodology and a sequential exploratory mixed methods design. Table 6 outlines the structure of the research study and key aspects of the design which will be elaborated throughout this section of the chapter. The top row of the table presents how the research study started with an examination of international and national literature on the political and pedagogical developments in education underpinning the Victorian Tech School initiative, as well as constructivist theories of learning. Key themes which emerged from the literature and a pilot study informed the design of the conceptual framework. The conceptual framework was subsequently broken down into two analytical frameworks. Analytical Framework 1 focussed on layers of pedagogy in Tech School programs. Analytical Framework 2 focussed on the institutional relationship between industry and secondary schools, mediated by Tech Schools. These frameworks were used for cross-case analysis, following the primary analysis of case study data using triangulation.

In Table 6, case studies are divided into Tech School sites on the left of the table and secondary school sites on the right. The type of data collected is listed for each site as well as the method of primary, secondary and tertiary analysis. The last step in the research process involved generalising the main conceptual findings from the research with reference to the education literature in the Chapter 7: Conclusion.

Table 6
Structure of the Research Study

<table>
<tr><th colspan="2">Literature reviewed</th><th colspan="2">Frameworks developed</th></tr>
<tr><td colspan="2">-Socio-technological context of education in the 4IR
-Constructivist and critical theories of education
-Tech School impacts: programs, pedagogies, PL and school-industry partnerships</td><td colspan="2">-Conceptual framework (Tech Schools as mediating organisations)
- Analytical Framework 1 (programs and pedagogies)
-Analytical Framework 2 (inter-institutional relations)</td></tr>
<tr><th colspan="4">Research sites for case studies</th></tr>
<tr><td>Tech School A
(case study 1)
3-day program</td><td>Tech School B
(case study 1)
3-day program</td><td>Secondary school A and Tech School A (case study 3)
-Industry competition in school
-co-design workshop at Tech School 1</td><td>Secondary school B
(case study 2)
Four-day STEAM festival</td></tr>
<tr><th colspan="4">data collection method</th></tr>
<tr><td>-Standard evaluation criteria for recorded observations
-Student survey
-Interviews with: Tech School educators and director, student group, school teacher</td><td>-Standard evaluation criteria for recorded observations
-Student survey
-Interviews with: school teacher, Tech School educators and director</td><td>-Recorded observations
-Interviews with: student group, school teacher and industry representatives</td><td>-Recorded observations
-Student survey
- Interviews with: student groups and school teachers</td></tr>
<tr><th colspan="4">Primary analysis of data: Case study results</th></tr>
<tr><td>Mixed methods triangulation</td><td>Mixed methods triangulation</td><td>Within-method (Qual) triangulation</td><td>Mixed methods triangulation</td></tr>
<tr><td colspan="4">Interviews from participants in all sites triangulated and synthesised (case study 4)</td></tr>
<tr><th colspan="4">Secondary analysis of results: Cross-case analysis</th></tr>
<tr><td colspan="2">Case study 1: cross-case analysis of both Tech School programs using Analytical Framework 1</td><td>Case study 2: cross-case analysis with case study 1 using Analytical Framework 1</td><td>Case studies 3 & 4: Secondary analysis using Analytical Framework 2</td></tr>
<tr><th colspan="4">Tertiary analysis: Synthesis and final discussion</th></tr>
<tr><td colspan="4">Findings from cross-case analyses are related to the education literature using the conceptual framework of Tech Schools as mediating organisations for changing school pedagogy & structure.</td></tr>
</table>

Methodological congruence.

Table 6 presents how the research study was designed for methodological congruence through identifying key areas requiring research, collecting data through specific cases and then relating the findings from the cases using the analytical frameworks. Employing a mixed methods comparative case study design allowed for *flexibility of data collection methods* to adapt to the different contexts studied. Yet, maintaining an *overall focus for the research* was paramount, especially as the study was an exploration of Tech Schools as a new phenomenon in education. Richards (2013, p. 34) describes this fit between method and purpose for research as "methodological congruence". As there was no existing research on Tech Schools, *developing an understanding* of what Tech Schools were, and what need they were addressing in education, came prior to *identifying a research problem* to be investigated. The research problems – stated as sub-questions – emerged from the pilot case study findings and were refined through the trail of inquiry created by new case studies. The early development of a conceptual framework and its elaboration through the analytical frameworks was an essential part of the project. Integrating the case study findings into the framework clarified the formerly theoretically identified concept of Tech Schools as *mediating organisations*.

Case Study Designs.

The case studies were designed based on two factors:

1. Purpose: Providing opportunities to collect data that best met the stage of investigation to answer the research question.
2. Convenience: Information gained from meetings, interviews and previous research suggested upcoming projects which could serve as suitable case studies.

A basic structure of the case study progressions is included in Table 1, Chapter 1. A more detailed description of how the case studies were designed based on purpose and convenience is now provided.

Pilot study: Prior to formal case studies, a number of informal observations of Tech School programs were undertaken as well as conversations with Tech School educators. The research plan was discussed with the director and the head of programs from Tech School A as this was the main data collection site for the case studies. From this established relationship, a pilot case study was conducted at the main Tech School site. The purpose of the pilot study was to test the data collection tools, and Analytical Framework 1 for mixed-method triangulation. These tools were then refined and used for future case studies. Five other programs were researched at this site over the year.

Due to thesis space restrictions only one program is included from this Tech School, which was used for cross-site evaluation with Tech School B.

Case study 1: Cross-site evaluation of two Tech School programs. Criteria for evaluating project-based pedagogies and STEAM program design were developed by the researcher to objectively compare different programs for strengths and weaknesses. This standard evaluation was triangulated with student survey data and interviews with teachers, students and Tech School educators as primary data analysis. Initially, evaluations of STEAM programs in five Tech Schools were planned, but due to the closure of Tech Schools during the COVID-19 epidemic, visits were suspended. Data already collected from two Tech Schools for 3-day programs was used for comparison. Analytical Framework 1 was used for secondary analysis. Interviews with Tech School educators and directors as well as school teachers focussed on exploring the specific affordances of Tech School STEAM programs and how they could be embedded into secondary schools. These interviews were utilised for case study 4.

Case study2: School STEAM festival. An interviewed school teacher from case study 1 suggested researching their school STEAM festival. This teacher was part of the Tech School curriculum committee and programs advisory board. She was involved in the development of the Tech School STEAM programs and the STEAM festival in her school. Through the involvement of this teacher, a research relationship with the secondary school was developed. This included a survey of 159 students which was collaboratively created with teachers from this school. A report of the case study findings was presented to teachers and the school principal at a meeting to provide the school with feedback and further the impact of the research. From the large survey, responses from the 60 students involved in the case study were filtered to ensure a match between quantitative and qualitative data used. This survey did not contribute to the submitted journal article in Appendix G. Part of the article is presented in chapter 5 of this thesis as the results for case study 2.

Case study 3: Industry engagement. A key finding from case study 2 was that the school found creating authentic connections with industry and community challenging. This problem had been a feature of previous research by the Australian Industry Group (2017). One key finding from the literature was that an intermediary organisation could broker this school-industry connection. The potential for Tech Schools to mediate the partnership between schools and local industries became the focus of this third case study with two aspects highlighted.

The first part of the case study was an examination of Tech School A's co-design of programs with local industries. An observation of a co-design workshop and an interview with participating industry representatives were used to examine how local industries were involved in designing STEAM programs. The second part of this case study was a competition designed by Thales Australia and Tech Schools, run for secondary school students. A case study was conducted with one participating school which included observations, interviews with students and the school STEM teacher. The purpose behind combining both aspects of industry engagement: program design and involvement in a school-based design competition, was to present an example of how industry can be involved in school projects for increased authenticity and student agency.

Case study 4: Opportunities and challenges of school STEAM projects. During the collection and analysis of interview data from case studies 1, 2 and 3, a number of themes emerged from stakeholder interviews regarding the role of Tech Schools as mediating organisations for STEAM projects in secondary schools. The depth of insight from a broad range of stakeholders in Tech Schools warranted a separate case study as they had not been addressed through the design of the previous case studies. Case study 4 allowed for the participants in the study to have a voice in the thesis which spoke beyond the researcher's own framing of the research study. It expanded the breadth of understandings by drawing on the unique perspective of diverse stakeholders, each with a different agenda and opinion regarding the Tech School initiative. 30 interview transcripts from school teachers, interdisciplinary school leaders, student groups, industry representatives, Tech School educators and directors were synthesised using NVivo to generate key themes. These themes provided new insights on the case study findings and contributed to the research conclusions in Chapter 7.

Case study 5 (not included in the thesis): Interdisciplinary STEAM unit. Through the process of researching the Thales industry competition, a professional relationship was developed with the participating school STEM teacher. Tech School A and the researcher worked in partnership with the STEM teacher to develop a unit plan and curriculum documents to maximise the learning impact of an interdisciplinary STEAM unit. Due to COVID-19, the school was shut down and the case study was interrupted.

Over the period of school closures, rubrics which aligned Tech School projects with the Victorian Curriculum were collaboratively developed by the researcher and the Tech School. These rubrics, as well as an interdisciplinary unit plan were created to support school teachers assess student learning in projects against multiple subject descriptors from the curriculum (see Appendix E-STEAM unit plan and Appendix F-Generic STEAM rubric).

Research settings.

Research was conducted in two Tech Schools and two secondary schools in regional Victoria. Tech School A was used as the main research setting for multiple case studies of 2-day and 3-day programs, PL workshops, co-design workshops with industry, competitions and outreach programs. This site was used throughout the research study. Tech School B was researched for the cross-site evaluation (case study 1) using a standardised evaluation framework. This Tech School was studied over five days.

The secondary schools studied (also known as colleges) were local to Tech School A. Both schools were examples of large public colleges for students in Year levels 7-10. These were built between 2008 and 2012 as part of a city-wide education plan, in which four colleges replaced multiple smaller secondary schools. The schools were open-plan with large work spaces. Areas used for the research study were a STEM classroom, an art room and general learning spaces. Both schools had a range of technologies such as a laser cutter, micro-bits, LEGO engineering kits and 3D printers. These were mainly used for technologies subjects rather than integrated into other subjects.

Sampling of participants.

The participants used in this research study were:

- 5 Tech School educators
- 2 Tech School directors
- 2 Tech School program designers/head of programs
- 12 school teachers
- 3 interdisciplinary leaders
- 4 groups of approximately 5 students
- 5 industry representatives

- 4 surveys of approximately 25 students in each (Year levels 7-10)
- One survey of 60 students extracted from a survey of 159 students (Years 7-9)

Two of the school teachers in the study contributed to the development of Tech School programs through their involvement in the Tech School curriculum committee and the programs advisory Board (PAB). These teachers had comprehensive knowledge of the Tech School initiative and using the design thinking process for STEAM projects, with one teacher teaching STEM as a subject. Other teachers participating in the study had different levels of familiarity with Tech Schools, technology and STEM which was reflected in their interview comments. They taught a variety of subjects such as mathematics, science, art and the humanities, although predominantly teachers from STEM related subjects accompanied students to the Tech Schools for 3-day programs.

Students who participated in the Tech School 3-day programs (case study 1) had different levels of knowledge of STEAM and design thinking. Case study 2 had a mix of students from Year levels 7-9. For case study 3, many of the students were part of a STEM elective subject and had some prior experience of coding and manufacturing technologies. Greater detail is provided about the student and teacher participants for each case in Chapter 5: Results.

Ethical considerations.

The research study was approved by the La Trobe Human Research Ethics Department – Ethics ID (HEC19012). Some modifications to ethics were made during the research project to include interviews with industry representatives. There were no ethical issues related to this study. All participants received participant information statements and withdrawal of consent forms and returned signed consent forms. No participants withdrew from the study.

Data Collection Methods.

This was a mixed methods study using interviews and observations for qualitative data collection and surveys for a mix of qualitative and quantitative data collection.

Observations.

An observation schedule was used to record hand written field notes. This included notes on the behaviours of the students and the educators, with particular focus on the main educator's pedagogical decisions, their actions, conversations with individual students and whole class dialogue. These observations were later transferred into a digital Word document. Writing field notes by hand in a small exercise book was an unobtrusive portable method of recording, allowing the researcher to move freely around the class, talk to the students and the teachers. The observations were thus *interactive*, with the researcher adopting the role of a "participant observer" asking questions to students, but not prompting any form of behaviour or action during the lessons (Creswell, 2019, p. 215). Students and teachers were informed that the researcher would be taking notes and that observation records were mainly focussed on how the lesson was taught, rather than what the students were saying and doing. Students seemed comfortable to share their work and thoughts during the lessons.

Tech School program observations were analysed using standard evaluation criteria and organised under key themes for triangulation with interview and survey data.

Interviews.

Interviews with students were mostly conducted in focus groups of four to six students during class at school at a convenient time for the supervising teacher and students. The audio recorded interviews lasted approximately 15-20 minutes. The interviews were semi-structured, with 6-8 questions targeting specific themes from the analytical frameworks and additional questions in response to participant comments. Organising the questions into consistent themes allowed for responses to be triangulated with other data collected on the same themes.

Teacher interviews were conducted individually at their secondary school and at the Tech School. These interviews ranged from 15 minutes to 30 minutes as some teachers were eager to speak in greater depth about their participation and perspectives on the Tech School programs. These were generally teachers who were involved in the program development of STEAM projects. Interviews with Tech School educators and directors were conducted on site, usually at the end of an observed program.

Thematic analysis of interview data.

All interviews were transcribed by the researcher and a copy of the transcript was sent to the teachers if they wished to receive a copy. NVivo – a digital data analysis tool – was used for case study 4 which consisted of a large quantity of transcribed text. This was an *inductive approach to analysis* with themes emerging from the data.

For case studies 1 and 2, key sections of transcribed interviews were triangulated with survey data and analysed observations using analytical framework 1. This was a *deductive approach to analysis* with theory generating themes which emerged through a synthesis of constructivist theory prior to the analysis of data. These themes served as categories for organising data and "analytical codes" to review interviewee comments (Gibbs, 2016, p. 59). Using analytical frameworks supported the synthesis of cross-case findings from multiple case studies (Saldaña, 2016).

Surveys.

Tech Schools collect large sets of quantitative data through student satisfaction surveys to evaluate the success of their programs. These are part of key performance indicators (KPIs) reported to the Victorian DET. A review of the survey questions used by participating Tech Schools revealed that the questions *were too broad* to account for the meaningful differences between programs and the multiple reasons for students' positive and negative comments. For this reason, modifications were made to one Tech School's existing student survey for the study which was also used in the other Tech School to ensure that the data collected could be triangulated and compared across programs. Refer to Appendix C for survey questions and responses from Tech School B's program.

The final design of surveys was a standard 5-point Likert scale with some comment boxes administered online through Google forms. Through trial and refinement, the scale for each question was designed to be *unidimensional* by measuring only "one thing at a time" (Cohen, Manion, & Morrison, 2018, p. 480). Overall, making the survey quick and easy to complete and encouraging students to leave comments was favoured as the survey data was triangulated with interviews and standard evaluations from observations.

Section 4: Data Analysis and Synthesis

Analysis was undertaken in three stages: primary analysis using triangulation, secondary analysis using the analytical frameworks for cross-case analysis, and tertiary analysis using the conceptual framework for synthesis and to relate the findings to the literature. Undertaking analysis in stages promoted the development of a *narrative* to explain the multidimensional construct of a mediating organisation (Saldaña, 2018). Situating participant perspectives within a broader narrative of constructivist education through the frameworks reflected the dialectic of constructivism between the "paradigmatic or logico-scientific" and the "cultural or narrative" which relates to Bruner's studies in psychology (1986, pp. 9-10). In this way, rich and insightful participant perspectives from interviews provided a human *narrative* for the study. Conversely, the *paradigmatic* structure of the frameworks allowed the subjective participant perspectives to be related to theory. An outline of the method for each stage of the analysis is provided and its purpose.

Primary analysis.

Primary analysis in case study 1 consisted of mixed methods triangulation structured using key themes from the analytical frameworks. Synthesising and organising constructivist theories into the structural dimensions of the analytical framework provided standard criteria to evaluate and compare Tech School programs and pedagogies (included in Chapter 5). This *standardised evaluation* was reductive in its omission of the unique context of each program such as the type of students, teachers or the theme of the project itself. To overcome this limitation, specific examples from the programs were included for each of the criteria, as well as triangulation with interview and survey data. The purpose and use of standard criteria are elaborated in a later section on triangulation. *Triangulation of data* was also used as primary analysis for case studies 2, 3 and 4 presented in Chapter 5. This primary analysis as part of the presentation of results was necessary, to enable secondary cross-case analysis in Chapter 6.

Secondary analysis.

This method of analysis was conducted after the primary analysis was complete. First, program evaluations in Tech School A and B were compared using Analytical Framework 1 to provide a general evaluation of Tech School programs in case study 1. The same framework was used for secondary analysis of case study 2 allowing for *cross-case analysis* of the 4-day festival (case study 2) with the 3-day Tech School programs from case study 1. Case studies 3 and 4, were synthesised using Analytical Framework 2 to explore themes such as the development of an inter-institutional learning community (ILC).

Tertiary analysis.

To draw broader conclusions about themes across the cases, the cross-case analysis findings were *synthesised using the conceptual framework*. This allowed for a broad overview of the mediating role played by the two Tech Schools in supporting a range of educational activities such as program design, pedagogy, professional learning, industry engagement and the development of resources to support teachers embed projects into their schools. Tertiary analysis situated each case study on a scale of impact for Tech Schools from: delivering in-house programs (shallow) to providing service and resources for in-school programs (deep). This *cross-case synthesis* was then considered with *reference to reviewed literature* to broaden the scope of Tech School impacts from: local school support (narrow) to advocating for project-based learning in industry and community contexts (broad).

Conceptual Framework.

The conceptual framework was informed by literature on the *political context* of education and *constructivist theory* of education. The Tech School initiative embodied a dialectical relationship between both facets of education: politics and research. As the research moved from a study of the literature to a study of the main Tech School site and its relationship with local secondary schools, the dialectical relationship was conceptually refined to consider Tech Schools as *mediating organisations*.

The conceptual framework with Tech Schools as mediating organisations was divided into *project-based pedagogies* and *inter-institutional engagement* as interrelated activities of Tech Schools researched through case studies. These served as central propositions to explore internal theoretical relationships in the conceptual framework (Anfara & Mertz, 2015, p. 3). Two analytical frameworks were developed to investigate these internal relationships of pedagogy and institutional engagement using case study data. During the analysis of data from case studies 2 and 4, the connection between Tech School *programs* and school *curriculum* emerged as a key theme which was integrated into the conceptual framework. This represents the development of the frameworks and the data analysis as an iterative cycle involving a methodological dialogue between deductive and inductive research (Quay, Bleazby, Stolz, Toscano, & Webster, 2018).

The changing nature of the teaching *profession* towards interdisciplinarity and greater engagement with industry was a second theme raised during interviews with educators regarding PL to meet 4IR professions. These themes sit outside the central focus of the conceptual framework, yet they play an important role in understanding the political-pedagogical context of Tech Schools. These themes are presented in the outer layer of the conceptual framework to consider the dynamic relationship between the

Victorian Department of Education (DET), the *Victorian Curriculum*, *constructivist theories of education* and the changing capabilities of teachers in *professions* undergoing transformation. These exterior aspects of the conceptual framework bind the internal connections between central activities of Tech Schools as mediating organisations.

For a comprehensive description of the conceptual framework and detailed explanations of the two analytical frameworks refer to Chapter 3 of this thesis.

Triangulation.

Building a case for education change through multi-layered triangulation.

Tech Schools' focus on fostering entrepreneurial capabilities over subject content is an example of changing education to match the predicted needs of a changing society. This requires systemic reforms at multiple levels of policy-making and school management (Fullan, 2015). The difference between making a value judgement and *making a justified argument* depended on the theoretical and empirical soundness of the data and the validity of the methods used for evaluation. For this reason, understanding clearly why Tech School educators taught a certain way; why certain types of knowledge were prioritised and integrated into projects; and why the Victorian Government implemented the Tech School initiative required research which was *multi-dimensional*. The research also needed to be *multi-layered* to critically evaluate the participant beliefs relative to the norms of their institutions which were shaped by the broader political context. Undertaking this multi-layered and multi-dimensional evaluation required triangulation of different participant perspectives for *nuance* as well as triangulation between methods of data collection for *rigour*. Both aspects of the evaluation depended on collecting reliable data. How triangulation addressed specific *issues of reliability* is now elaborated in relation to case study 1 which focussed on evaluating the quality of Tech School programs and pedagogies.

(i) multi-participant triangulation.

Tech Schools generate large quantities of data, yet, using data for evaluation requires a *reliable source*. Regardless of the quantity of data, averaging does not result in reliable conclusions if the source of the data is not reliable. An example of this, is the student satisfaction surveys run by Tech Schools. These aim for a high percentage of "satisfaction" from students as evidence of success. These surveys generate thousands of responses from students which is extensive data. Yet, as one Tech School educator noted "We could feed the kids sausages and they would have satisfaction but it has nothing to do with learning”. To primarily use these student satisfaction surveys as a source of data for program evaluation is *unreliable* because the evaluation is based on the students’ perspective, whereby “student satisfaction” is incorrectly correlated with “program quality”. As this example demonstrates, reliability of data is central to a valid evaluation of Tech School programs. How the shortcomings of the surveys were addressed will first be discussed, followed by the issue of determining *program quality*.

The limitation of surveying students for evaluating program quality was addressed by triangulating the perspectives of students, teachers and Tech School educators. This revealed points of similarity and difference on the quality of programs and pedagogies from *different data sources* as emergent themes. Further, accounting for the participants’ institutional context was important for the triangulation of data when there was a misalignment or “interference” between the findings of research such as different teachers’ perspectives of quality education (Flick, 2018, p. 120). These interferences reflected more broadly the historical and political context which implicitly constructs notions of authority, achievement, expertise, accountability and valued knowledg*e* (Freire, 1998; Giroux, 2001; Sarup, 1978). Part of determining the agendas which governed the opinions and behaviours of the participants was to become familiar with the education *paradigms* they were are part of, including the rules, beliefs, instruments and standards used (Kuhn, 1962/2012). In-depth ethnography involving multiple field studies of the main Tech School over the period of a year and an extended case study with one secondary school provided rich qualitative data to compare the different paradigms that secondary school teachers and Tech School educators operated within (Creswell, 2019; Merriam, 1998).

(ii) triangulating subjective and objective evaluations through mixed methods.

Triangulation of different perspectives increased the reliability of the evaluation of programs by verifying whether one participant’s version of quality agreed with another. Yet, *verification* through a relational construction of subjective perspectives did not resolve the issue of evaluating ‘quality’ in any *standard sense*. If the multiple sources of data were triangulated, yet, all sources could not individually be relied upon as being objective, then how could the conclusions reached from the results be relied upon? Overcoming this problem required synthesising more reliable sources of data to construct a *generalised standard* for evaluating quality pedagogy and program design in Tech Schools.

This created a need for a *standard measure of quality* for comparison with participant perspectives to overcome the issue of triangulation as a form *of synthesised relativism*. Triangulation of constructivist theory through an in-depth review of literature allowed for the identification of key themes. Once key themes were established, synthesising key principles from theory allowed for the development of standard criteria of success. In this way the process of *theoretical triangulation* mirrored the process of *empirical triangulation* (Thurmond, 2001). Evaluations using the standard criteria were triangulated with data from surveys and interviews allowing for a juxtaposition between objective and subjective evaluations of quality.

Through the development of standard criteria of quality, the issue of determining reliability of participant perspectives was overcome. Establishing the reliability of the criteria for evaluating the quality of pedagogy, program design and more broadly the educational aims of Tech Schools (from a constructivist perspective) was a substantial part of the research process. While the standard evaluation was only used for case study 1, it represents an attempt to *objectively compare* different project-based programs for quality. This is an essential step towards making a justified claim for project-based learning in schools. Analytical framework 1 for triangulating objective and subjective evaluations is also a contribution to constructivist research in education. For this reason, detail is provided regarding how the standard criteria was developed.

Standard Criteria for Evaluations of Quality.

Standardised criteria were used as a means of determining quality or "merit determination" of pedagogy and program design in STEAM programs observed in Tech Schools (Davidson, 2005, p. 131). This complemented the rich qualitative data collected through interviews as well as survey data. The development of standard criteria for evaluating constructivist pedagogies in project-based programs was an iterative process. First, literature on conducting program evaluations (Owen, 2006), evaluation methodology (Davidson, 2005) and evaluation as a discipline (Scriven, 1991) were consulted. Then, key themes which emerged from review of constructivist literature were incorporated into Analytical Framework 1. These *themes* were then refined through observations of Tech School projects in pilot studies. This was followed by a further examination of literature with a focus on generating multiple specific examples of successful constructivist pedagogies which became *criteria for evaluation*. These criteria were synthesised and structured into a one-page table based on the key themes from the analytical framework.

The standard evaluation table was tested by examining observations from multiple programs at Tech School A to provide feedback on the programs delivered over the course of a year. A further test of the standard evaluation table for reliability of method and results was conducted by three educators from the same Tech School (Riege, 2003). This was undertaken as the Tech School had been seeking a method for the educators to *self-evaluate* their pedagogies and gain *peer feedback* using a consistent method. The educator evaluations were synthesised into one document and compared with the researcher's own evaluation as a form of "investigator triangulation" to determine whether similar conclusions would be reached by different educators and the researcher (Flick, 2018, p. 13). Having a standard form of evaluation allowed for common themes to emerge from the Tech School educators' separate evaluations. These educators also provided feedback on how the evaluation process could be improved, especially as a self-reflection tool for teachers.

Based on the educators' feedback, the standard evaluation template was simplified for usability, including establishing a visual representation of successful aspects of pedagogy as a *heat map* through highlighting the criteria. As each aspect had five key criteria, highlighting criteria on the one-page evaluation table allowed for quick comparison between programs with 1 or less criteria being met (highlighted in pink) 2 or 3 criteria being met (in white) and 4 or 5 criteria being met (highlighted in green). Examples of these highlighted tables are included in the Chapter 5: Results. As Davidson notes this type of quantitative determination of success is a "fairly blunt instrument" (2005, p. 136). Yet, it provided a quick overview of areas needing further investigation through written examples of what success or failure looked like. These evaluations were then synthesised into a master table of successful constructivist pedagogies with specific examples from the programs (Appendix D2). Results from triangulating the standard evaluation with survey and interview data are included in Chapter 5, case study 1. Completed tables used for triangulating mixed data are included in Appendices A and B. Table 7 presents the template used for the standard evaluations in this study.

Table 7

Standard Evaluation of Constructivist Pedagogies in Project-Based Programs

Personal Layer: Individual learning	
Program promotes ***student agency*** by encouraging students to: (1) develop new concepts and explore relationships between ideas (2) set & reflect on, and communicate personal goals (3) consolidate learning individually & with others (4) represent learning in varied ways such as stories, images, models (5) make choices in what and how they learn based on interest	Educator makes ***personal connections*** by drawing upon students': (1) interests, daily experiences, prior knowledge (2) peer groups, family, community groups, school (3) beliefs, thoughts, ideas, feelings, motivations, values (4) knowledge of professions and future plans (5) The educator's background was communicated to the students
Opportunities for ***personal growth*** of student capabilities through: (1) inquiring, questioning, measuring, testing and critiquing (2) developing and communicating new knowledge (3) collaborating with others (4) engaging in creative expression and construction (5) independently sourcing information and problem solving	Educator ***differentiates the program*** to meet specific student needs by: (1) providing supporting resources & tools to scaffold learning (2) extending student thinking with questions, hypotheses & discussions (3) teaching strategies for problem solving (4) using open problems to encourage students to construct knowledge (5) giving individual feedback to students
Lesson Layer: Relational learning	
Students interact as members of a ***learning community*** using: (1) diverse & creative ideas (2) student feedback on success & failure, and peer teaching (3) sharing, collaboration & voluntary participation (4) empathy & cooperation (5) roles, routines, procedures relevant to the learning context	The lesson reflects ***authentic work place practices*** such as: (1) meetings & conferences (2) formal & informal presentations (3) evaluations, critiques & feedback (4) schedules, milestones & deadlines (5) negotiating rules & common values
A ***range of forms of assessment*** used for student learning include: (1) using explicit learning objectives as criteria (2) self-reflections & peer assessment by students (3) assessment by Tech School & class teachers (4) student development of capabilities (5) use of knowledge, skills & tools to solve real-world problems	Features of the ***learning environment*** utilised for active learning include: (1) varied learning spaces & furniture (2) ready availability of materials, low & high-technologies (3) tools for different purposes: new skills, curiosity, independent work (4) student-directed learning rather than lectures & demonstrations (5) authentic industry practices modified for student participation
Project Layer: Collective learning	
Students involve themselves in the project as ***team members*** by: (1) emotionally & intellectually identifying with a common problem (2) sharing knowledge & ownership of project amongst all members (3) fairly dividing the labour amongst members (4) valuing the input of all members and utilising their expertise (5) coordinating individual actions to achieve the goal	***Tools & resources enhance learning*** outcomes by enabling teams to: (1) produce quality prototypes & convincing solutions to problems (2) learn new skills & knowledge transferrable to other tasks (3) support independent problem solving and ownership of learning (4) externally represent & communicate their knowledge (5) rethink & improve prior knowledge through designing, building & testing
The project ***promotes diverse skills*** by encouraging teams to: (1) investigate, research, interpret & experiment (2) question assumptions, critique ideas and consider alternatives (3) utilise the affordances of materials, technologies & theory (4) use a variety of means to design solutions to problems (5) reflect on what the group learned and how to improve	The design of the project ***relates school learning to society*** by: (1) requiring authentic solutions to actual community/industry issues (2) allowing students to share their knowledge with the community (3) embedding the school curriculum into practical experiences (4) drawing on the latest technology and knowledge used "in the field" (5) suggesting ways that the project can further learning in/out of school

Chapter Conclusion

This chapter has situated the research study within a constructivist paradigm. The epistemological foundations for constructivism and its suitability for the study have been outlined. The choice of a sequential comparative case study using mixed methods was justified for investigating the central research question. The development of a conceptual framework to explore the new concept of Tech Schools as *mediating organisations* was explained. The subsequent division of the conceptual framework into two analytical frameworks for studying pedagogy and institutional engagement was outlined with reference to their internal dialectical relationships. The design of the research study and its stages was diagrammatically presented with a focus on methodological congruence between: the literature; the frameworks; case studies selected; settings and participants; data collection methods and multiple levels of analysis. Details were provided on each of these aspects of the research study including the challenges and opportunities of mixed methods triangulation and standardised evaluations. Chapter 5 will provide descriptions of research in each of the four case studies and primary analysis of the results.

Chapter 5: Results

Introduction

This chapter presents results from four case studies. For readability, each case study is structured with: an introduction; context and program description; results overview; results mediating factors; emerging insights and implications for the next case study.

Four case studies are resented in this chapter:

1. Project-based pedagogies: Comparison of program delivery in two Tech Schools
2. Secondary school STEAM project: 4-day STEAM festival
3. Inter-institutional relations: Tech School co-design and competitions
4. STEAM in schools: Interviews with teachers on challenges and opportunities of running STEAM programs and how Tech Schools support them.

Justification for the case study designs.

The four case studies were designed as examples of key mediating activities undertaken by Tech Schools. Case studies 1 and 2 focus on STEAM pedagogy and program design in two Tech Schools and a secondary school. This allows for close analysis of the mechanics of designing, implementing and evaluating constructivist project-based STEAM programs. Case studies 3 and 4 take a broader perspective of Tech School mediation between schools and industry. Case study 3 provides practical examples of how to utilise industry effectively for authentic programs and competitions. Case study 4 examines the strengths and challenges of integrating these projects into the school setting.

The progression through case studies 1-4 also reflects the research process of using insights from a case study to initiate an inquiry into a different area of Tech School mediation using a new case study. In this way the case studies are both *elements* situated within a conceptual framework and *milestones* in a sequence of research.

Through the organisation of data, some preliminary analysis is presented in this chapter. In the context of this research study, this is called “primary analysis”. For example, case study 1 involves an evaluation of two Tech School programs by utilising standard criteria as well as triangulation of data. This primary analysis was necessary to move to secondary cross-case analysis in Chapter 6.

Case Study 1: Two Tech School Programs Compared

Introduction.

This case study evaluates two 3-day programs run in two different Tech Schools. By repeating an identical evaluation process in two different settings, comparative analysis could be conducted in Chapter 6 to ascertain common strengths in Tech School programs. This enabled some generalisation of principles of pedagogy and program design, as well as highlighting specific differences in both programs. The case study is organised with an evaluation of program 1 in Tech School A, followed by an evaluation of program 2 in Tech School B. Surveys, standard evaluation tables and triangulation tables are included in Appendices A-D.

To ensure that the evaluations were conducted rigorously, observation data was analysed using standard criteria which was then triangulated with survey and interview data for both programs. Chapter 2 provided theoretical justification for the evaluation criteria and a template of the criteria was presented at the end of Chapter 4. Refer to Appendix A and Appendix B for examples of the collected data.

Context and Programs.

A core aspect of Tech Schools is the delivery of multi-day programs for students at the Tech School facility. Each Tech School develops different programs, yet some features are common across programs:

- 2 and 3-day programs are structured in stages from the design thinking process
- Programs address one of six industry foci identified by the Victorian Government
- Programs include the use of state-of-the-art technologies such as laser cutters, 3D printers, coded robots, AR, VR, media editing software and other digital design programs such as CAD
- Programs are usually co-designed with a local industry and reviewed by teachers

Programs can differ between Tech Schools based on: the local demographic of students; local industries; the program developers' interpretation of the design thinking process and the background of the Tech School educators who deliver the programs as well as the Tech School director's own educational philosophy.

The two 3-day Tech School programs presented were delivered in two different Tech Schools. Program 1was a 3-day tourism project requiring 20 Year 10 students to design an augmented reality (AR) experience for visiting tourists. Program 2 was a 3-day poverty inquiry requiring 18 Year 10 students to design an urban architectural feature to support homeless, vulnerable or disadvantaged members of the local community. Program 1 had a focus on using a specific piece of technology for a broad theme (tourism) with students producing an AR digital prototype. Program 2 was more flexible in the technologies available (laser cutting, 3D printing), while having a more specific focus on students designing a physical prototype.

Results: Overview of Program 1

The table in Appendix A2 uses colour coding to present the overall pedagogical strengths of this 3-day tourism program as well as areas which were not strong. Key evaluation criteria from the table are italicised in this presentation of results.

Strong aspects of the program (table cells shaded with a green background) are:

- The program provided opportunities for *personal growth of student capabilities*
- The lesson encouraged students *to interact as members of a learning community*
- The lesson reflected *authentic work place practices*
- *Features of the learning environment* were utilised for active learning

The overall aspect of the program with the most pedagogical issues (shaded with a pink background in the table) was:

- The educator not making *personal connections* with students or between students and the topic. This is evidenced by missed opportunities to draw on the students' interests, daily experiences and prior knowledge. Further, the Tech School educator didn't share his background which included working in media and digital arts industries. As a central aspect of the program was using a green screen and media editing software, sharing his professional background would have been good for making a personal connection with students.

Specific examples of pedagogical strengths (highlighted in green) and aspects to be reviewed (highlighted in red) are included in the findings from synthesising the standard evaluation and triangulated survey and interview data. The standardised evaluation was compared with interview data from the Tech School educator who ran the program; the visiting secondary school teacher; student survey results and a follow-up interview with four students who participated in the program. The 12 criteria headings from the standard evaluation (and Analytical framework 1) were used as a means of organising the data into a single table for triangulation as well as for direct comparison with the standard criteria. Refer to Appendix A1 for the triangulation of survey and interview data using the standard criteria table.

Results: Mediating Factors.

Synthesising standard evaluation with survey and interview data.

The complete evaluation of program 1 is now provided by comparing the standardised criteria analysis and the data triangulation analysis. The three layers of pedagogy and 12 criteria from the standard evaluation table are used as subheadings to integrate and compare the mixed data, with key criteria italicised. Cross-case analysis of the two Tech School programs is conducted in Chapter 6 using Analytical Framework 1.

Personal Layer: Individual learning.

Student agency: Learning autonomy was promoted through opportunities to independently experiment with technology. Time for experimenting could be increased for student engagement. Students were given freedom in the way they worked with others to develop ideas and consolidate their learning. 30-second elevator pitches at key stages during the project were an effective way of having students consolidate their learning. The standard evaluation suggested that student agency could be increased by supporting students to independently plan and complete the tasks. Providing an opportunity for students to personally set and reflect on their own interests and goals would help to personalize learning for the students. The school teacher commented “you want to build the resilience to have the force to break through it, but you need to give them the resources for it.” Overall, the students were satisfied with the program (75%) but 25 % of students were dissatisfied, which suggests some issues related to engagement.

Growth of capabilities: This was a strong aspect of the program according to the standard evaluation, as well as student and school teacher comments. Nearly all the students (90%) felt that they had learned something new. According to the class teacher:

> The biggest challenge for the students was coming up with the problem. This was different to school, where students were usually told what to do and what problem to solve. So, coming up with their own problem to solve, is remarkably difficult for them.

Promoting new ways of thinking about the issue using different strategies was valuable for student growth. The Tech School educator stated that more creative thinking strategies could be used, including a "range of techniques such as the SCAMPER technique of modifying, replacing and substituting could provide different directions for creating beyond ideating.",

Personal connection: This was a weak aspect of the program according to the standard evaluation as well as student and school teacher comments. Mostly, students were not interested in the program but were satisfied with the Tech School staff. 80% of students thought that they would *not* want to explore further any of what they experienced at the Tech School. The Tech School educator stated "We need a stronger 'why' introduced at the beginning. For students to see why this is an exciting industry with some examples of other projects, to help them excite, ignite and engage." Yet, according to the school teacher there was excellent engagement from challenging students. The school teacher stated that he was "impressed with the engagement of some of those kids. Particularly students who rarely produce work that they would be happy to present to others." According to the standard evaluation, one area that seemed to be neglected was building a rapport with students by sharing relevant experiences for a personal connection. The Tech School educator could also have asked students about their interests and experiences to build a better rapport, as well as involve the class teacher to help challenged students to better understand the user's problem.

Program differentiation: The standard evaluation found the program was excellent for extending confident students, but lacked support for struggling students which resulted in high levels of frustration for some students. This was reflected in the survey, with half of the students finding the program too difficult. This suggests that there needed to be more scaffolding, such as trouble shooting guides for design and technology issues, to help students who were struggling. One interviewed student commented that:

> Sometimes we didn't know what we were supposed to do because there was too much freedom. We didn't really get the help we needed, he was always pushing us along the path, to solve it yourself to learn.

Having opportunities for students to work at a different pace and providing resources for problem solving technology would differentiate learning, to extend or support where needed. The class teacher stated:

> The program itself, needs a bit of work. The app design one. Because for three days it felt like it was getting a bit stale. That is a long time to spend on just that one topic. Also, some background information around the different tech would help some visiting teachers to feel more comfortable supporting students at the Tech School.

Possibly, teachers could be provided with some background resources prior to attending such as online tutorials or a learning and teaching booklet.

Lesson Layer: Relational learning.

Learning community: The standard evaluation suggested that overall, this was a strong aspect of the program. The program was successful in using design thinking terminology which according to the school teacher,

> is useful as a structure, to have a common vocabulary right across the school. Then we can build on it, and as teachers the more we become exposed to it, the better it will be for us and for the kids to hear that common vocab.

In addition to using a common language, different peer interactions used to promote a learning community were observed throughout the program. For example, students from another class tested the groups' AR apps and gave feedback. This was an effective way of providing a real-world example of market testing. According to the standard evaluation, the one feature which could be improved was promoting voluntary participation by students.

Assessment of learning: The student prototypes and pitch presentations served as real-world informal assessment. The school teacher commented:

> I liked the fact that they actually built something. Even though some groups did it to a higher level. They all actually ended up making something that was augmented reality and they actually achieved something.

Yet, this work could be used as summative assessment if it was connected to the curriculum through a school unit of work. The school teacher noted:

> It needs to be very specifically curriculum-based for teachers, otherwise they think it is not getting anything done. It is a massive thing as there is pressure for it to be right as it is a document going out to parents.

Embedding the project into a school unit with some pre-work and curriculum-connected assessment could have improved buy-in from students and the school teachers in building a stronger connection to school learning.

Authentic practice: Based on the standard evaluation, this was a strong aspect of the program. Having project milestones, conferences and presentations added authenticity which is often lacking in class due to time constraints. The school teacher stated:

> It was great to see them have the time, even though it was sometimes too slow. To actually have the time to sit down and do a project over three days is amazing. Compared to here, we have 70 minutes.

The school teacher felt that it was important for the Tech School "to show the kids the different areas they can end up by going through a STEM pathway. And that is where they are going to have an impact." Making a stronger link between the program and the different types of professions could add authenticity and increase student aspiration in STEM.

Learning environment: The facility space and new technologies were a highlight for the students and the school teacher and were noted as strong aspects of the Tech School on the standard evaluation. The student survey indicated that satisfaction for the facility was high to very high. No students expressed dissatisfaction. The Tech School educator stated that the strength of the Tech School is "providing access to high functioning technologies" and an "alternate approach to learning, including the physical space and the length of the program." The standard evaluation indicated that the delivery of the program needed to be more hands-on with less lecture-style presentation of content. The program had too many lengthy teacher presentations where students were sitting passively. This was also noted by the school teacher's comment that "they need to try and get past that theory part and get them actually hands-on doing something. And something big, a bit earlier."

Project Layer: Collective learning.

Team membership: Allowing students to choose their groups was valued by students with 80% of students finding working in teams easy. According to the Tech School educator, collaboration was not always successful with students adopting "school-leadership styles of group work." The Tech School educator stated that "students are most challenged by the open nature of the program and expectations around collaboration." The students informally selected roles at the start of the project. Yet, formalising these roles with an expectation of what each member should contribute could have helped the students think about expertise, accountability and inclusion of all members. This could have improved the fair division of labour in the project, which was an issue in some groups, as noted in the standard evaluation.

Diverse skills: According the standard evaluation, regular reflection throughout the program helped students consolidate their learning and review new skills. The Tech School educator stated that "Problem-solving was an area that students struggled with, especially collaborative problem-solving. The empathy and define stages of the design thinking process was also a challenge for students."

Possibly, these skills were underdeveloped because they were not a focus of school learning. In addition, having more diversity in ways to solve the user's problem could be one way of helping the students, as noted in the standard evaluation.

Tools enhance learning: According to comments on the student survey, using new technology seemed to be what students enjoyed most. All groups were using large touch-sensitive monitors connected to their tables. This was excellent for enabling students to collaboratively visualise the artefact they were creating. While technological tools were engaging, simple tools that support student independent learning were needed. This was an aspect requiring attention according to the school teacher and the researcher's evaluation. The class teacher stated:

> He [*the Tech School educator*] made a video of how to do something but then he never told the kids where it was. So, when the kids were stuck, they couldn't go back to it to help themselves. They were always waiting on him.

To avoid this issue, trouble-shooting guides and videos, which are important learning tools should be easily accessed by students.

Project relationship to school & society: About two-thirds of the students said they would *not* like to do this sort of project back at school. According to the school teacher, making stronger links to STEM professional pathways would increase student interest and aspiration:

> Few students are aware of the wide range of jobs that are related to STEM. For students, when you say engineering, they only think of standing on a welder. They think it is the only job that goes with that profession.

Student motivation in STEM could be improved by showing students “all different possibilities out there that they can go through” (school teacher). Further, the standard evaluation suggested that making a link between the Tech School project and the types of learning at school could have made the project more relevant to the students.

A summary and discussion of the results will be undertaken through a cross-case analysis between Tech School programs 1 and 2 in Chapter 6.

Program 2: Three-Day Poverty Inquiry Program

This program was run in a different Tech School to program 1. This program asked students to design a feature for an urban space to support homeless or disadvantaged members of the community. Students participating in the program completed some preliminary work in their humanities class at school.

The same data collection and analysis process was undertaken as in program 1. Refer to Appendix B1 for triangulated survey and interview data. The completed student survey for this program is included in Appendix C as an example of one method of collecting data. The standard evaluation table is presented in Appendix B2. Key findings are now presented followed by a summary of findings from the standard analysis and triangulated data.

Results: Overview of program 2

The standard evaluation table in Appendix B1 presents the overall pedagogical strengths of this 3-day poverty inquiry program as table cells shaded with a green background. These strong aspects of the program are:

- The Tech School educator *differentiated the program* to meet students’ specific needs.
- The lesson encouraged students *to interact as members of a learning community*
- The project *tools and resources enhanced learning* outcomes for the student teams

Overall, there were no aspects of the program with substantial pedagogical issues (shaded with a pink background). The weakest aspect of the program was the evaluation of student learning. This is explained in the synthesised evaluation below. Specific examples from the standard evaluation table of pedagogical strengths (highlighted in green) and aspects to be reviewed (highlighted in red) are included in the findings below.

Results: Mediating Factors

Synthesis of standard evaluation with survey and interview data.

The program was mainly run by one Tech School educator, although a second Tech School educator ran the Tinkercad workshop and team taught when required. As both Tech School educators were interviewed, they are distinguished by the numbers 1 and 2, with Tech School educator 1 being the main educator over the three days.

Personal Layer: Individual learning.

Student agency: According to both Tech School educators, allowing students opportunities for self-guided learning was important. "It is about giving them space to go off and develop their own skills" said Tech School educator 1. This was noted as a strength in the standard evaluation of programs. Yet, according to educator 2, "this can be quite overwhelming for everyone at the start." 72% of the students felt that they were able to share ideas about what they wanted to achieve in the program. According to the standard evaluation more opportunity for students to explicitly state their learning goals for the program would further enhance student agency. For example, at the start of the program, students could write down personal goals and make a daily plan of what they want to achieve. This might be in response to the following question: "What do you hope to learn, or achieve through this program?"

Growth of capabilities: Tech School educator 1 believed that learning growth required students to "move beyond the content and to focus on what it is that you are doing, what are the skill sets that you are practising here." Almost every student was satisfied with their Tech School experience (94%), although less students felt that what they had learned was new and interesting (67 %). While the standard evaluation didn't note a lack of interest as an issue, measuring, testing and communicating knowledge were noted as lacking. Potentially, these aspects could have been embedded in the Test stage of the design thinking process as a new capability for students to develop.

Personal connection: Only a little more than half of the students felt that what they learned will help them in future (61 %), which reflects a lack of connection between the program and the students' future plans. This is a surprising result as one of the Tech School educators was observed on a number of occasions discussing with students their career plans. Tech School educator 1 stated "Here it is about learning something new and getting those skills intact and applying those skills in something that they might be interested in."

Possibly having resources and making links between the program and professional pathways could be done more explicitly at this Tech School. For example, by putting up posters that describe the educators' backgrounds and interests related to STEAM as well as different professions related to the STEAM project. One example of making a personal connection noted in the standard evaluation, was when Tech School educator 1 assessed the students' prior knowledge by asking students about the prework they had done at school on vulnerable people and whether they had used block coding or Tinkercad before.

Program differentiation: This was a strong aspect of the program, according to the standard evaluation. 89 % of the students felt that they were able to do what the Tech School educators asked with help. Supporting disengaged students was a priority for Tech School educator 1:

> Sometimes for those challenging kids, the teacher can just give up. It is often like a domino effect. Once they start getting that train of thought, they don't have confidence in themselves and completely shut off. They don't think about the future and they don't believe in themselves.

According to the researcher's observations, having the students draw a *Solutions Tree* to empathise with the user; writing a "How can we…so that…" statement to define the problem; and using *SCAMPER* for ideation were good conceptual tools to build relationships between ideas. In addition, the Tech School educators provided individual support and ran a Tinkercad workshop. Some additional resources for independent problem solving could have been provided in the prototyping stage.

Lesson Layer: Relational learning.

Learning community: This was a strong aspect of the program, according to the standard evaluation. Developing a community of learners was promoted by encouraging students to share ideas and to collaborate, which was scaffolded through the design thinking process. Learning was also displayed by the Tech School educators who sometimes team taught and had different strengths. "Leadership have tried to hire people from very diverse backgrounds so that we can draw on people's expertise. So that has been really helpful to help each other out in those respects" (Tech School educator 2).

Assessment of learning: According to the standard evaluation, this was *not* a strong aspect of the program as there was no time for reflection by the students or any formal assessment of the students' development of capabilities. A booklet was supplied with some ways that student work could be tested, peer and self-evaluated. Unfortunately, the booklet was never used during the 3-day program, so the students did not test their prototypes by asking survey questions and receiving feedback from peers. In addition, some criteria for evaluation of the quality of the prototypes would have been useful in the Test stage and for summative assessment. Examples of criteria could be: simplicity of design and generating diverse ideas for prototypes. A lack of student assessment could be partly due to the school teacher not knowing the program well enough to link it to school learning. When interviewed, the school teacher did note that in future:

> You can incorporate this across the board. You can tie it to the curriculum and make the assessment something like this, where they are actually doing hands-on stuff. It can culminate in this being their assessment rather than a test. And for the kids the engagement is there.

Authentic practice: This was considered to be a strong aspect of the program, based on the standard evaluation. The lessons included milestones and deadlines which reflected authentic workplace practices. Tech School educator 2 believed this was a result of "looking at problems not as discrete subjects, but from a multidisciplinary angle, the way that we work in life." Also, "I think it is quite a mature environment, in the way that we approach the programs. That students are working on a project and can be quite self-directed in their learning" (Tech School educator 2). Further, the school teacher believed that having four lessons of pre-work using the booklet at the school added authenticity to the program through prior student understanding of "how you can raise awareness of homelessness and poverty in your community."

Learning environment: 83% of the students were very satisfied with the learning spaces and technologies. Most positive student survey comments were related to the use of technologies, especially 3D printing and CAD programming. The

Tech School educators kept their demonstrations and explanations short which allowed plenty of time for active learning by the students. As noted in the standard evaluation, the Tech School had an excellent workshop/makerspace set up which provided the students with plenty of construction materials and all the tools and resources to build both low and high-tech prototypes.

Project Layer: Collective learning.

Team membership: During interviews, Tech School educator 2 stated:

> I think working in teams can be quite confronting for students who are not doing it as much in their classrooms as we do here, when you are working on a project together and trying to come out with an outcome in a short space of time. And I think having to manage time as well.

95% of the students believed that they worked well together in a team. According to the standard evaluation, the multiple scaffolds used by the Tech School educators were a reason for the quality of teamwork. This included helping the students to empathise and collectively define the problem using a *Solutions Tree* and writing a "How can we…so that…" statement.

Diverse skills: According to the standard evaluation, the students employed diverse transferrable skills such as: investigating; researching and experimenting as part of the design/innovation process; team collaboration and communication; as well as developing technological skills in 3D printing and laser cutting. There could have been more critical thinking promoted by the Tech School educators regarding the potential effectiveness of the solutions and whether alternative solutions could be more impactful. Tech School educator 2 mentioned that:

> Experience of the skill development that we are trying to focus on can be quite confronting for some students. The technology, the digital literacy skills we are trying to develop and when you are exposed to a lot of new technology in a short space of time.

Tools that enhance learning: The school teacher valued the unique experience provided for student learning. He noted "Getting them out of the classroom and doing hands on stuff like this while tackling the theory side of it first, I think this is a really good way to deliver any sort of curriculum to the kids." This learning experience also extended to the school teachers' learning:

> The teachers come here and get a taste, they see the pedagogy in play and how the kids are involved in the programs, the computer programs, the materials, the laser cutting and they now know that all of these resources are now here. (Tech School educator 1)

Based on the standard evaluation, this aspect of the program was noted as very strong, with resources provided for student ownership of learning and communication of learning through the prototypes. Having more strategies for solving technological and technical problems could have helped students who sometimes had to wait on the expertise of the educator to solve a tech issue. A simple trouble shooting guide might have helped the students to independently solve problems.

Project relationship to school & society: The majority of students believed that the solution they developed as a group would help an industry or community (78 %). The Tech School educators aimed to support a change to pedagogy in schools through project-based learning. "We are getting away from that subject learning, which is more multi-disciplinary" (Tech School educator 2). According to Tech School educator 1:

> This is just a taste for teachers for how they can utilise this type of thinking and teaching pedagogy into their own particular subject. It gives them some ideas of how they could run their humanities class or their science class in a different way.

According to the standard evaluation, this impact on school learning could be enhanced by further embedding the project into a school unit of work. The authenticity of the project could also be enhanced with some presentation of work to industry and community. According to the school teacher and Tech School educators' comments, both recommendations are being explored by the Tech School for future iterations of the project.

Further discussion of the results will be undertaken through cross-case analysis between the two Tech School programs in Chapter 6. Using Analytical Framework 1, specific pedagogical differences between the two programs will be discussed and general themes of Tech School programs will be outlined.

Emerging Insights from Case Study 1.

This case study sought to provide insights on Tech School pedagogies and program design. Evaluating project-based programs run in Tech Schools required different criteria of quality pedagogy. Using standard evaluation criteria based on constructivist theory enabled pedagogy and program design to be evaluated across three layers: individual, relational and collective learning. One emerging insight from the standard criteria was that it allowed for strengths and weaknesses in both Tech School programs to be *directly compared*. This was supplemented by the triangulation of interview and survey data which provided the perspective of students, teachers and Tech School educators. This established rigour through a *multidimensional approach to evaluation*.

The presentation of results revealed that Program 1-Tourism Showcase had a well-structured program in terms of providing *authentic practices* and developing a *learning community*, but lacked connections between the program and the students' own background. Program 2-Poverty Inquiry had greater diversity of strengths across pedagogical layers including *differentiation*, development of a *learning community* and *use of tools*. These strengths in the program were partly attributable to their structure based on the design thinking process as well as providing *authentic projects* based on community/industry issues. Generally, the Tech School programs demonstrated sophisticated use of tools and the learning environment which can be attributed to their purpose-built *maker spaces* and advanced manufacturing technologies.

Common weaknesses of the programs such as a lack of assessment and connection to the Victorian Curriculum were noticeable, which reflects the perspective of Tech Schools as *curriculum enhancing* rather than *curriculum delivering*. This is potentially attributable to Tech School programs being an excursion rather than an integrated part of schooling. Whether this is sufficiently impactful for teachers to integrate the programs into their own schools is explored in case study 2. A comparison between Tech School and secondary school STEAM programs is undertaken in Chapter 6 Analysis.

Implications for the Next Case Study

The emerging insight from case study 1 regarding strengths and weaknesses of Tech School programs, led to an inquiry into how STEAM projects can be run in secondary schools. This informed the selection of case study 2: a four-day secondary school STEAM festival. This case study was run in the school that attended Tech School program 1. Interviews with teachers who ran the STEAM festival and who attended

Tech School programs, provided comparative data for the analysis of case study 2 as well as case study 4 in Chapter 6.

Case Study 2: Using the Design Thinking Model for a STEAM Festival

Introduction.

Case Study 2 documents the implementation of a four-day STEAM festival run in a public secondary school in Victoria which used the design thinking process to structure student projects. It addresses the opportunities and challenges of implementing project-based learning in a secondary school. As the STEAM festival used the design thinking process to implement a Tech School project, this enables comparison between the school program and the programs run in two Tech Schools in Chapter 6.

The case study is presented as an excerpt from a journal article written by the author, currently under review. For the full article including an introduction to literature on STEAM, please view Appendix G. Presentation of the case study as part of a journal article provides an alternative method of examining project-based learning to the standard evaluation and triangulated survey and interview data used in case study 1. Further, presenting the results as a sequence through the design thinking process better suited the article format, than grouping according to the analytical framework. The qualitative case study approach to researching the STEAM festival with its emphasis on a small group of participants as a "bounded system" suited the contained structure of the journal article (Yazan, 2015, p. 139). Finally, conducting cross-case analysis of case studies 1 and 2 tested Analytical Framework 1 as a flexible means of integrating diverse case studies for analysis.

The case study presents researcher observations and interviews with five students and four teachers involved in the STEAM festival to highlight key insights related to opportunities and limitations of running a co-curriculum STEAM event. Participant interviews were triangulated with observation recordings and survey data. The survey was developed with the school teachers and completed by 159 students from multiple communities (school houses). The responses from the housing project group (60 students) were filtered out from the main survey allowing for correspondence between survey responses, observations and interviews. Thematic analysis was undertaken to elicit key insights which included *student agency*, *integration/interdisciplinarity* and *authenticity* in the journal article. As with case study 1, this primary analysis was necessary in preparation for secondary cross-case analysis in Chapter 6.

The theme of *interdisciplinarity* is elaborated in the full journal article in Appendix G, by considering how specific links to the Australian Curriculum could be made in each stage of the design thinking process. This is summarised in a table as a resource for teachers undertaking industry/community-based STEAM projects.

Context and Program.

The festival was held in the last week of term in a regional 7-10 secondary school (college) in Victoria. The four-day festival was a whole school event involving all Year 7, 8 and 9 students (approximately 500 students). Year 10 students were away on work-experience. During the festival, usual classes were suspended. The case study focussed on a group of 60 students from one of the four school communities, who undertook a housing project. This small case study is presented because it is an example of a low-stakes approach to transdisciplinary STEAM, using a design thinking process which other schools could implement. It also represents typical limitations of time and assessment of projects in transdisciplinary projects (Herro & Quigley, 2017). Proposed solutions to the issues raised in the case study are provided in the full article (Appendix G) as a scaffold for teachers embarking on interdisciplinary STEAM projects.

Results: Overview of the Four-Day STEAM Festival.

Observations and interviews with participating teachers and students during the STEAM festival provided two key insights:

- The STEAM project was engaging for students through the exploration of a real-world issue (authenticity), working with friends (social learning) and having choice in what and how they learned (agency).
- While some teachers felt that the STEAM festival was authentic to industry, it was limited by time and lacked assessable outcomes (curriculum alignment). They felt that a project embedded into subjects over a term could allow for reporting against the curriculum (interdisciplinarity).

Results: Mediating Factors.

Teacher planning for the festival.

Two weeks prior to the festival, teachers from science, mathematics, English, the humanities, technology and the arts met three times to map out the logistics of running the project. These planning meetings enabled teachers from different domains to work and learn together which one teacher described as a rare opportunity. The four-day housing project was a version of a program run in their local Tech School. This provided the teachers with a project which had already been tested with different groups of students as well as templates on the design thinking process.

Interviewed teachers valued the meaningful learning experiences that transdisciplinary STEAM projects created for the students through real world connections to industry and community:

> That is the point of it anyway, that when you go into any industry, you work across. You don't just work in any one area. Which is another argument for why we have had to move away from STEM into STEAM, because when we were just teaching STEM to get a better PISA rate, the cracks were starting to show. (Arts domain leader)

To address this issue, the festival was seen by some teachers as a trial for developing an integrated program embedded into the school timetable involving cross-disciplinary collaboration between teachers:

> We can easily marry English and the humanities together or maths and science together and set them off on their ways and get them to team-teach. But we are not actually doing a true integrated program. We're not really representing industry or what really happens in a workplace. (Arts domain leader)

The potential for increasing student engagement through integration was also mentioned by a number of teachers:

> I think we need a more balanced curriculum here. I think we are too maths heavy. We have double the time in Maths and English compared to any other subject. But they are not usually the engagement subjects, why students are here. Students come to school to learn English and Maths because they are told it is important but it doesn't keep them entertained. (Mathematics and science teacher)

Yet, translating a festival into an integrated unit was seen as posing some logistical challenges:

> It is one of those things that is always talked about, those integrated units. it is easy to do it with a small group of kids. But we want it to be equitable, so the challenge is when we have 250 Year 7 kids who are all working through a sustainability project. (Music, humanities and digital technologies teacher)

These and other comments by the teachers suggested that the transdisciplinary STEAM festival was seen as a step towards delivering a more integrated curriculum until the school leaders were ready to make structural changes to the timetable.

Day 1: Empathise and define.

Groups of two to three students undertook a range of brainstorming activities on affordability, homelessness and sustainability to explore the topic of housing. For one group of students this was a powerful connection:

> We came up with the idea of building a unit to help single parents and their children in need as they don't always have the money or things to cope. My mum is a single parent. I kind of thought: she has a lot of stress to try and put shelter over us. So, it would be a lot easier for other single parents who are in a worse position than us to have some kind of shelter until they can get on their feet and try and find a place. (Year 8 student)

This student comment demonstrates how a project can empower students to reflect on personal issues and *empathise* with other members of the community. These personal student connections were then related to the ethical issue of social housing by having a guest speaker present on the issue of homelessness in Australia. The students researched statistics related to the issue of homelessness and different eco-friendly building options to create a *defining statement* of the issue for an individual member or members of the local community.

From a curriculum perspective, asking the students to consider social and environmental issues in defining their *user's problem* provided opportunities for drawing on the Capabilities from the Victorian Curriculum such as: the personal and social capability; ethical understanding as well as the cross-curriculum priority of sustainability. The students were given a booklet to record their ideas and to write a defining statement of the problem. Unfortunately, the booklet did not contribute to students' school reports. It was also one of the least popular aspects of the festival according to the student survey. Some survey comments noted that the booklet was confusing and did not seem to be an integral part of working through the project. This was also mentioned by one interviewed teacher.

One teacher felt that sustainable housing was a topic that fostered connections between the arts, humanities and STEM and would be well suited to an integrated unit using the design thinking process:

> Sustainability is a unit of work where the humanities are looking at climate and urbanisation. So, housing and sustainability come under that umbrella. In the Empathise phase, researching and understanding the problem. Applying what we know about insulation from research to the project as a prototype is really important and the humanities come through in that. And art as well follows that design process really well. (Music, humanities and digital technologies teacher)

This reflection and other quotations from teachers reveal an active interest in project integration using design thinking, although the logistical challenge was also a theme raised by teachers during the interviews.

Day 2: Ideate and prototype.

On the second day of the festival, the students visited a factory which makes sustainable "Tiny Houses" using compressed straw panels. The students toured the display yard where the Tiny Houses were assembled and asked questions about the design process, construction, cost and the sustainability of the materials used. This provided a tangible example of an innovative housing business.

Back at school, the students undertook an *Ideation session*, by generating as many novel ideas as possible, recording them on sticky notes and displaying them on a section of a wall. This interactive visualisation technique was followed by a process of synthesising and selecting the most innovative ideas to solve the user's problem, while also ensuring a prototype could be built over the next two days. The opportunity for teachers to observe the students collaborating and independently problem solving was considered valuable by the teachers. "I think the real plus is seeing kids working together. Having conversations. It is one thing to go up and ask a question, but just walking past and listening is powerful. To hear them in their own "kids-speak'" (English teacher).

Day 3: Prototyping.

Some groups of students began prototyping at the end of the second day. Other groups started on the third day. Prior to prototyping, the teachers reviewed the students' STEAM booklets and discussed their idea as *formative assessment*. Student prototypes included models of Tiny Houses, camper vans with solar panels, community housing for the homeless, and a variety of eco-friendly homes. Materials used were recycled cardboard, paint and ice cream sticks connected with hot glue. Most students were enthusiastic about having the freedom to create, although some students lacked confidence in their ability to construct. According to the student survey, prototyping was the most satisfying aspect of the festival as well as contributing most to student learning.

Day 4: Test, present and reflect.

The final day of the festival commenced with students completing the prototypes and the booklets. The other half of the day involved presenting the work and reflecting on the project. Part of the presentation of work required students to annotate their prototypes with descriptions of key features related to solving the problem. The prototypes were displayed in a large learning space with other school community projects in preparation for the next day's parent-teacher interviews.

Each group briefly explained their prototype to the rest of the community. Student feedback was given to groups verbally or written down on a form accompanying the prototype. Due to a lack of time, there was *no redesign or iteration* based on this feedback. The festival was completed with a whole community reflection on the challenges and successes of the projects. A lack of time to refine and iterate the projects was noted in the student survey comments as well as interviews.

Interviewed students shared insights on key themes from the festival. One common theme was the promotion of student agency and autonomy of learning through projects:

> Something that I learned personally was how to come up with a topic and then to branch out from that and get different ideas from it. It is important to know that you can do the project in many different ways. (Year 8 student)
>
> It allows us to develop at our own pace and reflect on our own skills. And of course, the support would still be there but we can work without relying on people and the teachers so much. (Year 8 student)

Further, the social benefit of working with friends was a common theme "It was good to do it over a period of time with people you feel comfortable with instead of people that you are forced to work with" (Year 7 student). Finally, the limitation of time for completing the project was noted "We would like more time if possible, because three to four days is not really enough time to do that sort of stuff" (Year 7 student).

Emerging Insights from Case Study 2.

Authenticity and agency.

The festival reflected many of the positive attributes of STEAM for building connections between disciplinary concepts such as ethics, design and technologies.

Connections were also built between the school, local industry and community through an excursion, guest speaker and a focus on authentic solutions-design practices. Utilising a program that had been developed by a Tech School promoted *authentic connections* to high growth industries such as: housing; sustainability and new energy sectors including solar power; eco-design and tiny houses; as well as community services related to supporting vulnerable groups. Unlike projects run in a Tech School, the prototyping was low-tech with a greater emphasis on the humanities and the arts through the process of defining the problem and prototyping. The lack of scientific and technological integration was seen as a limitation by one teacher:

> It was looking to me like an American science fair, where people make models out of glue sticks and things like that and they display them. I originally thought it was like a "wanna-be" Tech School. Where kids wanted to be in Tech but we didn't have the equipment or the resources or the know how to use any of it, so we use hot glue guns and paddle-pop sticks. (Mathematics and science teacher)

This raises the question: *What can schools offer for project-based learning compared to what Tech Schools can offer?* Potentially secondary schools are a better context for exploring the underlying issues to be solved through *deep subject-based learning*, while Tech Schools can be utilised for *high-tech prototyping* as a second iteration of the solutions design process. How both aspects can be aligned is presented in Appendix G.

Translating a transdisciplinary festival into an interdisciplinary unit.

The four-day STEAM festival represented a *transdisciplinary approach* to project-based learning. This allowed for natural links to be explored between key concepts from different subjects under an overarching theme of sustainable and socially-aware housing. This is different to i*nterdisciplinary projects* which explicitly connect content from the different learning areas. The use of the design thinking process allowed for a framework to sequence the project through stages which is a contribution to literature on transdisciplinary STEAM design. It also promoted collaboration between students and between teachers from the arts, science, technology and English which reflects *social constructivism* through STEAM (Kelton & Saraniero, 2018). Yet, the lack of explicit connections to the curriculum was a missed opportunity for summative assessment of student learning. This was largely due to a lack of time for exploring *connections between the design thinking stages and the learning areas* from the curriculum. Embedding stages of the design thinking process into subjects would draw on the distinctive expertise of teachers and would address the issue of lack of time:

> I found that with our group we have gotten to a stage now where we can start running some tests to see if it works. Once we can run a test to see if it works, then we can get to that next stage. But it has taken us a long time to get there. It has been predominantly building time up until now. (Mathematics and science teacher)

Further analysis of these results is undertaken in Chapter 6 using Analytical Framework 1 to compare the 3-day Tech School programs (case study 1) with the STEAM festival. Advantages and challenges of STEAM in either context will be highlighted. Appendix E is a comprehensive unit plan for a STEAM unit run in a secondary school.

Implications for the Next case Study.

Following this research study, the secondary school included in this case study has embarked on the journey of integrating STEAM into the timetable through the design thinking process. This represents a transition from *transdisciplinary to interdisciplinary* projects. Further, in collaboration with the author of this paper, the local Tech School has begun developing rubrics which align projects with the curriculum for year levels 5-10. Yet, an integrated model of STEAM might require a shift in how the school structures learning to make connections to curriculum and real-world learning in industry and community. According to Thomas and Huffman (2020) this can be a source of internal conflict in school leadership. This tension is explored in case studies 3 and 4. One way that schools were integrating projects was through engagement with industry competitions designed with Tech Schools. Case study 3 is focussed on ways that industry engagement could support authentic STEAM project-based learning through competitions and co-design.

Case study 3: Inter-Institutional Relations. Tech School Co-Design and Competitions

Introduction.

This case study presents two ways that Tech Schools connect school learning to authentic societal issues through engagement with industry. The first example presented is a competition co-designed between Tech Schools and Thales. This competition was developed in 2019 for Year 9 and 10 school students and run with support from four Tech Schools. The participation from students from one secondary school and one Tech School provides a qualitative study of the learning outcomes of an industry-based competition.

The second example is the co-design of a Tech School program with a focus on the involvement of local industries. The one-day co-design workshop with industry is considered to be a central process of Tech School programs and serves as a guide for school-industry engagement. Results for each of these cases are outlined separately. Chapter 6 will relate both activities using Analytical Framework 2 to draw out general themes for successful school-industry inter-institutional partnerships using Tech Schools as mediating organisations.

(i) Context and Program of the 2019 Thales Design Competition

The pilot competition was a collaboration between Thales – an international data, technology, sensor and engineering corporation – and four Tech Schools in Victoria. The competition theme was for students to design an innovative solution to a local issue using sensor technology "to make life better, to keep us safer" (https://www.thalesgroup.com/en/australia/news/thales-and-tech-schools-design-competition-kicks). Year 9 and 10 students from secondary schools worked in teams of three to six students to define a decisive moment, create a prototype solution and pitch the idea to a panel of judges at a regional presentation. The winning team then refined their prototype and presented at a state-level pitch final. The prize for regional-level winners was money for their school to spend on STEM equipment. The state-level prize for the winning team was a VR kit for each member of the team. All the finalist teams received support through an incubator or accelerator program to develop their prototypes with the potential of commercialising the product.

Each Tech School provided an immersion day for students from different schools with workshops in technologies such as sensor-tech, IoT (internet of things) and the design thinking process. The Tech Schools also provided 10 hours of technical workshops with industry mentors over a school term. The secondary school included in this case study allocated some time in school for participating students through a specialist STEM subject run by the coordinating school teacher for the competition. Students divided the projects into specific tasks within defined roles which were: solutions architect, designer and marketing manager.

Results Overview

Data was collected from researcher observations on the immersion day, a number of workshops in the Tech School and the regional pitch presentations.

Follow-up interviews with six students from different teams in one school, as well as the coordinating teacher from the school provided insights from the competition participants. Two themes seem to underpin the positive outcomes of the competition for student learning: *student agency* and *authenticity of learning*. The need to more fully *integrate the competition* into the school timetable and involve more teachers was another case study insight.

Results: Mediating Factors

During a group interview with the four finalist teams, the students described how personal experiences created an emotional drive to solve a community issue. These included: a pollen sensor to help people with asthma and allergies; a bushfire detector for rural properties; a bicycle crash emergency signal; and a sleep monitor for nocturnal epilepsy sufferers. These projects, based on the students' lived experiences demonstrate how *authentic learning* outcomes can be fostered through empathy. Examples include:

> My Grandma was a severe asthmatic and she always had to deal with taking lots of medication. And several team members also have asthma and are affected by pollen. So, we thought we could change people's life-styles, by having them not have to react to an emergency and be proactive. (Student from team 1)
>
> One of our team members was affected by the Castlemaine bushfires. We saw a big need in Australia, especially with all the bushfires. Not just with people but with animals and the environment and infrastructure. (Student from team 2)
>
> One of our team members crashed, riding his bike while camping, so he had to spend the night in a swag with a broken arm because there were no emergency services around him. So, we saw that there was a need for a bike sensor that could send a signal to someone else. (Student from team 3)
>
> A teacher at our school had a son, and he had epilepsy. It was nocturnal epilepsy, so it was in his sleep. She was nervous because she doesn't know if he is having a seizure if she falls asleep. Our epileptic sensor is connected to an accelerometer to measure the speed that your hand is moving. (Student from team 4)

These examples demonstrate the power of engaging in real-world issues through empathetic solutions-design. The following student comment encapsulates the importance of making a personal connection for authenticity, "It was for a purpose, because we had real people with real problems out in the world."

For these students, having *agency* over their learning distinguished this project from other school learning. As one student explained, "The fact that we were able to work on our own, without the teachers, but they were there if we needed them. It's an example of how self-directed learning (SDL) could actually be used."

According to the school teacher overseeing the projects, having industry experts available, ensured student success through targeted support. This overcame the issue of school projects that lack authentic outcomes for students. He noted that "Quite often the students don't end up with a tangible prototype in the end. The difference with the Thales project was that there were industry experts who came in." These included a *media producer who ran a workshop* on pitching and presenting, and *regular drop-in sessions at the Tech School* with a sensor technology expert.

Some difficulties which the students discussed in the interviews included the challenge of maintaining group cohesion over a long period of time, "We were good at the start, but we did run into some conflicts in the group. It is hard when we are working against each other but need to be working with each other."

Another issue brought up by the students was that some teachers – other than the volunteer STEM teacher – were not aware that these students needed time in class to complete the project:

> We kind of struggled in the time, as we didn't meet up outside of school as often as we should have done. And also, like what was said, the communication between the project and the teachers. Not a lot of them knew it was on, so some teachers thought we were just trying to get out of class as opposed to understanding it was a real competition that we are part of and we need time to work on it. (Student comment)

This lack of *communication and engagement as a whole school* is a common issue in integrating STEAM projects in schools according to the literature from Chapter 2 (Thomas & Huffman, 2020b).

The competition concluded with the regional finalist team – "The Pollenators" – pitching a more developed prototype at a state level competition. After the judging, the learning journey was not over for some students who continued working on their prototypes, as well as helping the regional finalist team to improve their prototype. This student describes her plans for the future, "We have decided that we would really enjoy taking our project to the next level." After the competition, this team participated in an accelerator program at the local university, and will possibly submit a prototype into a youth inventor's competition.

One missed opportunity in the design of the competition and its implementation in this secondary school was that: while the students demonstrated capabilities such as enterprise and communication skills; creativity and innovation; critical thinking; research and collaboration as well as significant content learning in a range of STEAM subjects, very little of this learning *contributed to student assessment and reporting* in school.

***Emerging insights for (i) industry design competition*.**

The Thales competition is an example of how *authenticity* can be fostered through student *empathy and agency*. Further, by providing industry expertise to support the design and construction process, the students actually built functional prototypes. The only limits to further learning for these students will be whether they wish to continue the process of building a commercially viable prototype and the level of support provided by the school and teachers. This competition is an example of the potential educational benefits of *scaling up*, to embed this project across a whole grade level and aligning it with the curriculum. Then, more students could experience this type of authentic learning, have more time in class to work on projects and have their growth assessed against the Victorian Curriculum. The possibilities and challenges of integrating project-based programs into schools are discussed in case study 4.

(ii) Context of Program Co-Design with Industry.

Each Tech School may approach program design differently. Yet, consultation with local industry on themes for student projects is common practice. The co-design process presented in this study serves as an example of authentic engagement with local industry and one Tech School by using a *design thinking process* to generate real industry issues to be solved by students.

Representatives from local industries including telecommunications, the Council, renewable energies, and mining participated in a co-design workshop on *new energies* and *food & fibre*. These two topics were identified as high-growth industry sectors by the Department of education and training (https://www.education.vic.gov.au/about/programs/learningdev/techschools/Pages/techschoolsedprogram.aspx). Other industry co-design workshops run by this Tech

School include: *medical technology & pharmaceuticals*; *advanced manufacturing*; *transport; housing & construction technologies;* and *Tourism*.

Results Overview.

The co-design workshop aimed to promote discussion between local industry representatives around common industry issues and opportunities to be developed into student programs. These programs encourage students to think about *work pathways* in local industries and for teachers to consider how Tech School STEAM programs could be connected to their class teaching. Further, there is the potential for innovative student solutions to be directly supported by industry and even adopted in practice.

Results: Mediating Factors.

Observations.

Data was collected through researcher observations and a 20-minute group interview with five industry representatives who participated in the co-design workshop. A brief summary of the observations is provided, followed by industry insights from the interview.

The workshop began with a tour of the different Tech School learning areas and a demonstration of equipment such as laser cutters, water-jet cutters and robotics. This was followed by a presentation on the purpose of the Tech School and the programs. Two Tech School educators facilitated the workshop. Some themes for discussion related to new energies were proposed such as sustainable energy sources, innovative technologies and future energy challenges. With regards to food and fibre, topics included: the use of IoT in agriculture; product traceability; future foods and future fibres. Based on their interest and expertise in these topics, the industry experts were asked to pair up for the remainder of the workshop.

The teams were given a quick technology challenge to experience the type of learning that the students would undertake in the programs. Teams were tasked with developing a simple prototype of a solution to an industry issue using small modular sensors, "littleBits". As these industry representatives had no experience in using the sensors and very little explanation was given, their initial reactions were uncertainty regarding how to achieve the task and in some cases mild frustration. Yet, most of the teams managed to independently problem solve and present a basic solution. The Tech School educator explained that learning through trial and error as well as collaborative problem solving were a key aspect of the student programs requiring a growth mindset.

During the remainder of the co-design workshop, the industry representatives worked through the seven stages of the design thinking process: *empathising* with a user; *defining* the issue; *ideating* possible solutions; building a simple *prototype*; *testing* the solution; *pitching* their solution and *reflecting* on what they had learned. The design thinking process was condensed with most time spent on empathising, defining and ideating due to the constraint of time and the focus of the workshop being on defining industry issues, rather than solving them. For a detailed evaluation of Tech School programs refer to case study 1. For explanation of the design thinking process refer to case study 2.

The teams were provided with a variety of high-tech and low-tech materials during the workshop such as: sticky notes; coloured felt pens; large sheets of butcher's paper; laptop computers; LEGO and littleBits sensors. The design thinking process was structured into short intervals of time ranging from three minutes to 10 minutes, with instructions and a template displayed on a projector screen. Overall, the pace seemed a bit rushed, although, given the short amount of time available, the fast pace was understandable. The level of engagement was high throughout the workshop, with industry representatives exchanging contact details and networking during the day and over the lunch break. All the ideas written on the sheets of butcher's paper by the teams were collected, prototypes photographed and key points from the pitch presentations recorded on paper to be referred to in designing the student program. After the workshop, five industry representatives volunteered to be interviewed by the researcher.

The industry issues identified as potential topics for students to develop solutions to included: a need for an IoT sensor system for detecting moisture in soil; monitoring and measuring carbon emissions; the capacity to charge electric vehicles in mines; labelling food products with a carbon footprint; and greater transparency in the supply chain from farm, to factory, to store. After the workshop, these topics were voted on by a programs advisory board consisting of teachers, academics and community educators. IoT in farming was selected as the final program, which was developed and delivered to students as an open problem at the Tech School. Over three days, the students designed a solution to the industry problem using technology, constructed a prototype and pitched the solution to peers and industry experts.

Interview.

During the 20-minute group interview after the workshop, the industry representatives shared insights on the co-design process and the connection between education and industry. Overall, they saw the Tech School programs as addressing a need for education to be more industry-relevant as new developments in industry require “upskilling, reskilling, changing jobs, changing roles and dealing with new technology”, as noted by one industry representative. Another industry representative stated that,

> there is a big gap in what you learn at school and university and what can be applied in the workplace. I think probably the curriculum development is a bit too top-down from government, rather than collaborating with industry and seeing what students are interested in learning as well.

The co-design participants considered preparation for employment to be shifting from a focus on technical skills, to developing capabilities such as a “growth mindset, where you can continually learn. Also, the ability to think innovatively. To think outside the box” (industry representative). Beyond creativity, key skills identified by industry included critically analysing information for truth-worthiness, problem solving and collaboration. They saw the Tech School as bridging a gap between education and industry, and addressing a shortage in the trade sector:

> There is a gap between what happens in traditional schools and industry. There is a bridge, but there is a big gap, as children are not taught to think like this. I think that it is really important. Hopefully this will help plug the gap. Yet this is a small plug in a big gap. I think there is a real role to play in the Tech School partnering with industry and exploring technology.” (Industry representative)

This comment highlights the *aspirational role* which Tech Schools have in drawing students’ attention to local industry careers.

The design thinking process utilised in the co-design workshop and the student programs, was considered a valuable way of fostering industry capabilities. “The real-world issues and the collaborative approach, the creative thinking and being prepared to fail and try again is really important. Certainly, for people coming into the workforce, that is what the workforce needs", stated one representative from industry.

The industry representatives also saw value in the co-design workshop for "linking up with people and finding out about the problems they are facing in industry and solving that using technology." In this way, the Tech School served as a hub for learning and sharing between industries.

Regarding how the workshop was run, feedback overall was positive. Some specific comments by the participants about the delivery of the workshop included:

> I would like more thinking time. The way it was structured was a bit of brain-dumping. (Industry representative)
>
> I think it was really fantastic. And the only thing I could think of to generate as many ideas as possible would be a bit more knowledge sharing between more than just two people. So, you all focus on one idea and everyone can share their idea to build on that. As with just two people, there aren't as many ideas shared. (Industry representative)
>
> The design thinking process: Ideation and a statement defining what the problem is; and the reflection. I think all of those things are imperative for work today. And to be able to collaborate and come up with ideas. (Industry representative)

As this industry feedback indicates, through co-design, Tech Schools have an opportunity to learn from industry representatives' perspectives of designing projects. This would expand the Tech School repertoire of design approaches beyond their standard model of design thinking and increase the authentic input of industry in the co-design process.

Emerging insights for (ii) program co-design with industry.

The co-design of a program, mediated by the Tech School was an example of authentically designing projects for student learning. The co-design process with industry ensured that student programs were *relevant to contemporary issues and technologies* and that local *industries had an active role in education*. It created a connection between local industries, community groups and the education system through genuine issues requiring solutions. The cycle of authentic learning was completed with students participating in the final program and presenting solutions to industry. This resulted in some student prototypes being adopted by local industries as solutions to existing problems.

Emerging Insights from Case Study 3.

This case study has presented two approaches used by Tech Schools to authentically engage industry with education. The results presented were descriptive with the intention of prompting schools to consider the use of industry competitions for *real-world learning outcomes* and to *directly involve industry* in the co-design of school programs. Both activities can be time consuming and daunting for school teachers and leadership, yet the structures and strategies developed by Tech Schools can serve as a template. Further, in both cases a Tech School mediated between industries and schools which suggests that having a *broker institution* is valuable in making the school-industry connection through projects. How Tech Schools can mediate between industry, community and schools will be further explored in Chapter 6 using Analytical Framework 2.

Implications for the Next Case Study.

Case study 3 provided examples of two different ways that Tech Schools foster industry and community involvement in schools. Yet, in both cases the *impact on the structure of schooling was minimal* as the competition and program co-design were not integrated into teacher planning or assessment and reporting. Based on this finding and the findings from case study 2-STEAM festival, a case study was commenced on the design and implementation of an interdisciplinary STEAM unit run in a secondary school. Unfortunately, due to COVID-19 the unit was interrupted mid-way. Yet, interviews with the participating teacher revealed tensions involved in implementing project-based learning in schools. As this had been a common theme in other interviews with stakeholders, case study 4 was designed to explore the *opportunities and tensions of project-based learning in schools*. How Tech Schools might mediate the successful integration of projects in schools was also explored through stakeholder interviews.

Case study 4: STEAM Education in the Context of Secondary Schools and Tech Schools

Introduction.

This case study sought to understand how Tech Schools support secondary schools to design and run interdisciplinary programs from the perspective of different stakeholders. 30 interview transcripts were synthesised using NVivo through a text search of key terms. The selected comments were then organised under themes of mediating factors to answer three central questions:

1. What are perceptions of different stakeholders on the challenges and opportunities of running interdisciplinary project-based STEAM programs in secondary schools?
2. How do Tech Schools currently support secondary schools by utilising unique affordances of the initiative and what are the limitations to this support?
3. How might Tech Schools support broader and longer-term structural changes needed for STEAM integration in schools?

Key themes in response to each of the three questions serve as headings, while subthemes which emerged through the synthesis are presented as subheadings. A total word count of 87604 words from transcribed interviews was narrowed down to 20885 words with NVivo and then organised into themes. From this selection, the most relevant quotations have been presented as results.

The triangulation of interviews from different contexts does not fit with the conventional notion of a case study as a situated and bounded unit of inquiry (Robert. E Stake, 1995). Yet, as Yin and other contemporary case study researchers note, situation and boundedness can be established through a research focus question or theme (Yazan, 2015; R. Yin & Davis, 2007; R. K. Yin, 2013). Case study 4 is an example of *using a theme to bound the data collection and analysis* into a contained area of study.

Finally, the unconventional use of extensive block quotations in the case study requires some justification. The reasons for presenting participant interview comments with minimal discussion are:

- To justify the conclusions and recommendations made in the thesis as being legitimately informed by the perspectives of the main stakeholders. This satisfies Yin's (2013) standard for the *internal validity* of case studies. Case study 4 enables an overarching *triangulation of reasoning methods* between (a) induction: the main themes emerge from a synthesis of the totality of interviews – and (b) deduction: the analytic frameworks designed by the researcher, informed by the literature.
- To establish a *narrative between the case studies* as each interview informed the types of questions asked in following interviews (Saldaña, 2018). This shaped the direction of the research and the design of the case studies. It also created an anonymous dialogue between stakeholders mediated by the

researcher through the selection of interview questions, based on emergent themes. Sequential block quotations represent this *conceptual dialogue*.

Context and Program.

The case study is a synthesis of qualitative data collected from interviewing:

- 12 teachers in separate interviews
- 3 interdisciplinary secondary school STEAM/STEM leaders
- 18 students interviewed in four group interviews
- 2 Tech School directors
- 2 Tech School program designers/head of programs
- 5 Tech School educators
- 5 industry leaders in one group interview

Some interviews were conducted at the Tech Schools following the delivery of two and three-day programs. Other interviews were conducted in secondary schools during the observation of STEAM units, festivals and events.

The results are presented in this chapter with minimal analysis. These results are further analysed using Analytical Framework 2 in Chapter 6.

Results: Overview.

The results from this case study are organised under three mediating factors as subheadings to provide insights on project-based learning in secondary schools. Mediating factor 1 provides stakeholder perspectives on the *opportunities* for student and teacher learning as well as *challenges* for teachers who run STEAM projects in their schools. Mediating factor 2 provides examples of Tech School *programs and professional learning* in technologies and design thinking which are current supports for teachers. Stakeholders commented on the limitations of the Tech School initiative due to a lack of integration into secondary schools. Mediating factor 3 considers the possible role of Tech Schools in mediating the development from traditional structures such as fixed timetables and subject-silos *to interdisciplinary industry-focussed programs*.

The presentation of the case study through participant quotations allows for insights to come directly from the key stakeholders involved: school teachers and interdisciplinary leaders; students; Tech School educators and directors; and industry leaders. As the interviews span a period of 18 months, some schools and Tech Schools have moved further along the process of integrating STEAM in schools. For this reason, these interview comments are especially relevant for schools who are at the start of the process of transitioning from subject-based to interdisciplinary programming.

One limitation of the case study is the absence of interviews with curriculum leaders in secondary schools who were *not i*nvolved with the Tech School programs. Interviews with secondary school principals or deputy principals are also lacking, despite being contacted by the researcher. This could be due to a busy schedule, or a reluctance to have their opinions recorded. Thus, apart from three school teachers, all other interviewees had attended the Tech School. As the focus of the research study is the role of Tech Schools in supporting teacher's development of project-based programs, having teachers who were familiar with Tech School programs and also having some experience with project-based learning is not considered to negatively impact on the results presented. Yet, it does reflect a *selective representation* of the participants from schools and industry who were enthusiastic to share insights based on their interest in STEAM and Tech Schools.

Results: Mediating Factors.

Mediating factor1: Interdisciplinary project-based STEAM in secondary schools.

What are perceptions of different stakeholders on the challenges and opportunities of running interdisciplinary project-based STEAM programs in secondary schools?

Time to plan, implement and assess projects.

Organisational structures were considered to be a major impediment to project-based learning in secondary schools:

> Schools have a big challenge. They need to stop looking at school as something that is defined by a timetable. That is really the only advice I can give them. That is what is stopping them from achieving better outcomes because individual subjects in timetables is not how the real-world works. The real-world works off a basis of project-based learning and that is where they need to go. (Tech School director)

A lack of reflection time was related to the timetable structure:

> Students need the time to reflect and to have their own type of reflection, process it, and then get back to it. To have that freedom, but in 70 minutes that is down to 50 after set-up and pack-up, you don't have the time to do it. (Mathematics and science teacher)

A lack of time for planning and implementing school projects was also noted:

> We were not given any time release or opportunity at school. We did what we could in the time we could find. So, it could have been done better. But we did get from A to B using the design thinking process, we did engage with industry, we did try to meet most of those criteria and we came out with a product. We ran out of evaluation time, and that is one of the things that I find happens a lot with these projects is the actual reflective process: Review, Refine, Re-think. "Where are we heading to, now?" always seems to be in the last 10 minutes. Even if it gets that amount of time, it is not scaffolded well. And the actual importance of it is never really stated. (Arts domain leader)

While time for planning and reflection were a challenge, the advantage for some teachers of project-based learning was in providing immediate feedback to students:

> With the school system there is so much curriculum packed-in that you do a test on something but you don't have time to go over the test to see what you got right and wrong and how you could improve on it. You don't get a chance to give them the feedback that they need. But with hands-on projects you can give them immediately the feedback they need. The kids take it on board and want to make it the best that they can. They actually listen to the teacher because they are invested in the project. (Science and STEM teacher)

A common theme in interviews was the overemphasis of meeting curriculum standards at the expense of authentic learning experiences in mainstream schooling:

> I think there is a big gap in what you learn at school and university and what can be applied in the workplace. I think probably the curriculum development is a bit too top-down from the government, rather than collaborating with industry and seeing what students are interested in learning as well. To change anything in the curriculum takes years and years, whereas technology for example, changes very quickly. So, education should be able to keep up with that more. (Industry representative)
>
> School is about engagement, but with maths and English we are measured on all these factors because the government says they are important so they are important. But they are not usually the engagement subjects, why students are here. They'll put up with English and maths because they are

> compulsory, but they are not here for that. So, at the moment we are skewed. (Science teacher)

Despite this enthusiasm for authentically integrating curriculum content into interdisciplinary units, aligning the project with the curriculum was a concern for some teachers:

> I think the biggest obstacle is trying to fit it into the curriculum. And trying to get teachers on board and to see that the assessment is not too complicated. (Science and STEM teacher).
>
> Teachers say that if it has a benefit, then it needs to be on the report and who then is going to report on it? It is a massive thing as there is pressure for it to be right as it is a document going out to parents. (Mathematics and science teacher).

According to one Tech School program manager, this means that for many teachers:

> They ultimately, because of time restrictions, look at the essentials because that is the curriculum. They can tick it off to prove that they have done it. So, they teach from a book or teach from a PowerPoint slide set. (Tech School head of programs)

Yet, shifting the paradigm of teaching from curriculum delivery to authentic projects would require,

> large-scale culture change because the media, the general public and the model of education we have in Australia. Rather, we should empower teachers as professionals instead of constantly putting them under the spotlight. To prove themselves, prove that they have delivered X, Y, Z. The idea that you start with curriculum and then work your way down to what you are doing in the classroom doesn't make sense. The last step is curriculum. Not the first step. (Tech School head of programs)

Further, the head of programs suggested that,

> instead, you go with teachers talking with other teachers in collaborative faculty meetings. Schools need to create time as there is barely enough time for faculty meetings, and it costs money or extra determination from the teachers. Once they know what the other subjects are doing, there is a lot of overlap in what they were recreating in a different format for their own subject. If you can create an interdisciplinary project running over different

> subjects, then each teacher can assess different components. (Tech School head of programs)

This comment demonstrates that Tech School educators considered project-based learning to be a realistic alternative to teaching in subject silos.

A generally expressed view amongst teachers, industry leaders and Tech School staff was the potential for using projects to develop and assess the capabilities from the curriculum:

> I think the purpose shouldn't be about the result being whether you could make it, but what was your plan, what did you make, what worked and what didn't? Let's evaluate. It's the critical thinking that needs to be assessed not the actual product. (Science and STEM teacher)
>
> The real-world issues and the collaborative approach, the creative thinking and being prepared to fail and try again is really important. Certainly, for people coming in to the workforce, that is what the workforce needs. So, it is a great way to train up for that. (Industry leader)
>
> What I would assess then is the capabilities. Looking at whether there is ethical understanding. Which we will start integrating into next year's programs because we really haven't done enough of that. Is there social and moral responsibility? Is there critical and creative thinking? And are we providing opportunities for that in the program? (Tech School director)

Based on these and other comments from interviewed participants, the role of Tech Schools in mediating project integration in schools emerged as a central theme for the research study.

The meaning of STEAM and how to teach it.

Both STEM and STEAM teachers were interviewed. In nearly all cases the STEM teachers felt positively predisposed towards working with the arts and humanities teachers under the title of STEAM rather than STEM. Yet, there were divergent opinions of how STEM and STEAM should be integrated within the timetable:

> My own personal belief and conviction is that STEM without STEAM is simply invention, rather than innovation. It's more than the simple capabilities of invention that are required. You need to be able to understand markets, you need to have a handle on economics, you need to understand the psychology of purchasing. You need to understand the role of packaging, branding,

> marketing, and those are complex and highly specialised skill sets. (Tech School director)
>
> That is the point of it anyway, that when you go into any industry, you work across. You don't just work in any one area. Which is another argument for why we have had to move away from STEM into STEAM, because when we were just teaching STEM to get a better PISA rate, the cracks were starting to show and studies are being done on that now. People were inventing things that had a Wizz Bang element, but no relevance to society. They weren't actually going to make anything better. (Arts domain leader)
>
> I think we are still on a journey to see where STEM fits. We have been moving it around to try and put it in a particular faculty. At the moment it falls under science; next year it's going to fall under technology. From my personal opinion, I think it should just be a standalone subject that covers multiple facets of other subjects, but shouldn't fall under a particular domain. (STEM teacher)
>
> I think that just like there is a maths coordinator and a science coordinator, a humanities coordinator and a health coordinator, there also needs to be a STEAM coordinator. And it needs to come out of being in a domain. To pull it out and give it its own feet. (STEM teacher)

One STEM teacher used competitions designed by industry and the Tech School for running his STEM units. He hoped to broaden the subject to include other subjects:

> I guess, that is where the industry program fits in really well, because it has brought industry into something that cannot always feel authentic. Because the students have had their own reason to choose it, they have done their own research into it and they have ownership of it as well. And it is great because it ticks our curriculum as well. Industry is there and the students are engaged and they get to be creative as well. And that hits the centre of the Venn diagram of good education, I think from my experience. (STEM teacher)

While having an integrated curriculum was noted as a positive development for schools, it was also seen as complicated by some educators and students:

> We can easily marry English and the humanities together or maths and science together and set them off on their ways and get them to team teach. But we are

> not actually doing a true integrated program. We're not really representing industry or what really happens in a workplace. (Arts domain leader)
>
> It just depends on which subjects are put together and which subjects are kept alone. So, I would like more science. Humanities shouldn't be with religion and healthy relationships. That is a subject that should be by itself. (Student involved in a new school interdisciplinary unit)
>
> I like the idea of multidisciplinary, project-problem-based learning in schools. It poses a challenge of how do you get depth in content. It poses another question, which is: Do you need the breadth in content? Is school really just learning how to learn? And I would suggest that, that is the model I would go with. (Tech School director)

This teacher felt project-based learning would require particular attention to structures for monitoring student progress:

> You can't have a school where kids are roaming all day. Because some kids will thrive, but there are too many kids who will fall through the cracks, where if there is any freedom then they will lose it. (Science teacher)

This school had been trialling the use of overarching themes as a multidisciplinary approach to integrating projects without disrupting the structure of subjects:

> The Year 8s this term, are looking at an over-arching theme which is: Do we shape the land or does the land shape us? With that, they are going to unpack the geography outcomes for the Victorian Curriculum. Obviously, we'll unpack tectonic plates in science and we will unpack geology and urbanisation. The STEAM project will be part of the Futures Cities project run by the Tech School. (School interdisciplinary leader)

These quotations from interviewed participants described the structural issues of running interdisciplinary projects in schools such as timetabling, resources and the curriculum. Teacher mindsets and attitudes about STEAM were also major themes of discussion and are presented separately.

Teacher capability and enthusiasm.

One issue which was discussed by participants was a lack of skill and confidence by teachers in technology and STEAM:

> Teachers love working together but they get scared stepping out of their comfort zone. Especially, when you start talking about something like STEAM. (School interdisciplinary leader)
>
> I think a lot of teachers are in the mindset that it is easy to give a test. "I don't want to do a project because it means that the kids will go off and do whatever." Having it structured would definitely help. I think that is the biggest issue, in that you need some form of project-based learning that is simple enough that everyone can learn it quickly and the kids can get involved. (Science and STEM teacher)
>
> I can think of some teachers who might not be onboard, but then they are there in every cohort. The ones who are afraid of trying something new. Which is a legitimate claim if it is interfering with VCE. But I think the majority of teachers would be onboard with something like this. (Humanities teacher after a Tech School program)
>
> The fact that it was multidisciplinary meant that the science teacher had to look into an ethics issue, or a humanities issue, or an economics issue. And again, that was challenging because they didn't want to expand outside of their realm. At the initial stages it was met with a lot of resistance because it was completely new. Teachers weren't familiar with it. They weren't comfortable teaching the content such as Tinkercad. It took a long time to get the teachers comfortable with the idea that they don't have to be the expert in the room. And that they could probably learn with the kid and help them. (Tech School program designer)

Despite the challenges and learning required, teacher motivation and mindsets positively changed when they saw the learning outcomes for students:

> The kicker was that the kids had to present their work in a massive exhibition, where we had on average about 400 people come through and look at their innovative products. Parents were listening to what their kid was learning, very much like the idea of a pitch but over and over again across multiple people. That caused a lot of attraction and helped the teachers to see how important this type of learning was. And that got them slowly onboard with what was going on. (Tech School program designer)

Some teachers felt that their own efforts to establish interdisciplinary projects in their schools had been impeded by the school curriculum leaders and senior management not engaging with new approaches to teaching:

> In terms of little people like us teachers trying to get uptake in curriculum and learning, we need it to come from the top and have them onboard. That senior management aspect is the most limiting out of anything. It is breaking my heart that I have my hands tied behind my back. It keeps me up at night because I want to provide those opportunities for my students to make those real-world links. (Interdisciplinary learning leader)
>
> It makes me wonder if I should invest so much time, only to be told by someone above me that it has to go away. The art faculty was so onboard with this at the start of the year and it was quite upsetting to tell them the program was cancelled. It was a shame because we had developed a really good rapport between domains, but then it was like snap, "We are not assessing against this." (STEM teacher)

These frustrations related to a lack of whole school engagement also applied to certain students' experiences. For some students who had participated in an industry-Tech School competition, a lack of awareness by staff in their own school was seen as counterproductive:

> We needed that communication with the teachers. And really just getting support from the school itself. Some teachers thought we were just trying to get out of class, as opposed to understanding it was a real competition that we are part of and we need time to work on it. Our STEM teacher was the main supporter for all of our teams throughout the project. Most of the other teachers were against him and thought he was crazy. But he did help out a lot, which was great. (School student)

One solution proposed by interviewed teachers was to have an interdisciplinary leader in schools working closely with Tech Schools:

> I really think it is important to have someone on the ground and I don't think it can just be a teacher. It should be someone in that middle management band that I am in and to push the people from the top. We, teacher ambassadors are all talking together and finding that leadership don't know what it is and they won't listen to what we are telling them. (Interdisciplinary learning leader)

> An ideal model would be to have a staff member allocated to lead that, whether it was myself or somebody else. There needs to be someone to run an integrated unit. They need to have that position of responsibility and some authority to call what is being assessed and how we deliver that. (STEM teacher)

These quotations capture a mix of emotions expressed by the study participants ranging from optimism to frustration, related to challenges and opportunities for interdisciplinary project-based learning in schools. Across the interviews, it seemed that the most frustration was expressed by teachers wanting to change the existing structures such as timetabling, assessment and integrating subjects but struggling to get traction. The types of support being provided by Tech Schools for teachers is the focus of the next section.

Mediating factor 2: Current support provided for teachers undertaking project-based STEAM units in their schools.

How do Tech Schools currently support secondary schools by utilising unique affordances of the initiative and what are the limitations to this support?

Programs in Tech Schools.

The affordance of time, curriculum and resources were seen as main advantages of attending a Tech School:

> The unique aspect about the programs running in the Tech School is that School leaders can see where STEM education is heading towards. Sometimes the teachers in the classroom can't see that happening. It gives them some ideas of how they could run their humanities class or their science class in a different way. So, they come here and get a taste. They see the pedagogy in play and how the kids are involved in the programs, the computer programs, the materials, the laser cutting and they now know that all of these resources are here. (Tech School program designer)
>
> I think the strength, certainly is the time. The fact that it is free, as well. Three days of workshop is phenomenal. That immersive, nature of the program and of course over three days, is potentially one of the strongest aspects. (Tech School educator)
>
> We are in the fortunate position to be able to invest in almost any sort of technology that we want, but we still need to be mindful that in order to cascade our skills out to schools it needs to be achievable for them as well. (Tech School director)

One Tech School provided schools with a booklet for pre-work prior to participating in the programs at the Tech School as well as assessment advice:

> We have spent about 4 lessons with this handbook, learning about hostile and inclusive design in community spaces. Then you move onto the next module: Empathy. Here we talked about the theories that everyone can be down on their luck. So, this book basically is used in the week leading up to here. (Humanities teacher)

Another Tech School was developing rubrics for teachers which aligned projects with the Victorian Curriculum:

> Instead of just going to the VCAA website where it is quite siloed, where there is nothing to support a collective STEM assessment, the rubric is a really powerful document for teachers. I also like that it starts with the design thinking model rather than the curriculum. And I still think our schools see curriculum as more important than skill. They start with trying to tick off the curriculum then wonder how they can fit problem solving into that. The paradigm is backwards. (STEM teacher)

The level of enthusiasm that teachers experienced in Tech Schools varied, often due to their level of prior knowledge:

> The teacher actually liked laser cutting, but that is a one-in-a-hundred opportunity. But we want to get all teachers in, not just design and tech teachers. We have some teachers who are not engaged at all and are not interested. We have chatted about why, and I have started developing some stuff for them because the biggest cause of disengagement for them is skills and knowledge. (Tech School educator)

Professional learning (PL): Technology and design thinking.

Tech Schools run a variety of PL platforms such as face to face workshops, online modules and software that is,

> all open and usable online for free. So, that way we can have more people doing it back at school and less of a worry about what group to send. (Humanities teacher).

This teacher wanted to embed the digital programs into his school subjects:

> We were talking about how, when we come back to school, we might need to build a bit more of a focus on Adobe Illustrator in our Year 7 and 8 multi-media class as well. If that is the way that the Tech Schools are going in terms

of laser cutting. So, aligning the tools that we use is beneficial. (Music and humanities teacher)

At the time of the interview in 2019, this Tech School head of programs wanted to expand the digital platform for supporting schools:

> Within the next 12 months I would like to see the stuff we do made available online, to increase impact with minimal extra work. So that we can access more people to create an awareness of the culture of the Tech Schools and the pedagogy behind them. Why not make it digital and freely available? We don't own any of it anyway. There are a lot of out-of-area schools. Having a digital presence could help, if we have certain programs that lend themselves to non-manual, non-hands-on stuff. (Tech School head of programs)

With learning moving to an online platform due to COVID-19, developing digital resources, PL and programs became a major focus of Tech Schools. The following insights were provided regarding how to support teachers' implementation of Tech School programs in their own schools:

> I think this is a really good way to deliver any sort of curriculum to the kids. You can incorporate this across the board. They're doing math, they're doing geometry, using measuring skills and in the humanities, tackling the issue of poverty which we are doing in Year 10 humanities. You can tie it to the curriculum and make the assessment something like this, where they are actually doing hands-on stuff. (Humanities teacher)

Further, integrating Tech School projects could overcome some limitations of running the programs solely at the Tech School. Examples of these limitations included time to complete projects at the Tech School:

> I thought that one of the things we would actually learn would be presenting and pitching. But we didn't get enough time to learn that. We had barely 10 minutes for the 50 odd kids we had. Sort of 2 minutes for each group. (Arts domain leader)
>
> Some schools won't engage with us because they can't afford the casual relief or the extras, other schools are just over-capacity already and it is hard for schools to put in the extra time for excursion paperwork which can be arduous. So, we are developing programs for them that we will take to their schools based around available technology that is easy to use, so that they can replicate our programs at low cost. (Tech School director)

Other teachers felt that with training in design thinking, they could make better learning connections for the students in their own schools than the Tech School:

> I think they need more facilitators at the Tech School, whether they are teachers or not, who can help by rotating around. Now that is not my job and I feel like I am treading on their toes a bit. I feel like they really need to have teachers as their facilitators. (Interdisciplinary learning leader)
>
> So, I think the Tech School needs to bring in more scaffolding. And I think that if they go down the pathway of being too fancy about it with these great interactive videos and all that sort of stuff, they're still not going to actually teach the process. (Arts domain leader)

Finally, the Tech School learning environment couldn't be as personalised as a school environment:

> This is still a new building but I kind of find that it feels a little sterile. The environment does and what we are doing doesn't feel comfortable. So, you have this ideal of what you would like, but then there is the reality of needing to get many kids through the door and they're from all different schools. (Tech School educator)
>
> It does have a bit of an exclusive feel about it. Even when you head-in, you feel a bit like you are locked in there. The way it is furnished has that exclusive sort of feel about it. The reality is that the Tech School needs the schools more than we need it. It is important to build a happy marriage or relationship, because we are saying let's work together and do something great together. (Music and humanities teacher)

This section has presented affordances as well as limitations of Tech School supports for schools. Yet, building a stronger link between the schools and the Tech School was a common theme that emerged during the interviews. This is discussed in the final section of this case study.

Mediating factor 3: Building a networked community of learning to support interdisciplinary programs in schools.

How might Tech Schools support broader and longer-term structural changes needed for STEAM integration in schools?

One novel approach was having Tech School student ambassadors teach their teachers in school:

> That is why we wanted to do the "teach the teacher" project. And I think that when it comes from the students who are excited, it is more meaningful if

> these students can showcase what they have learned. We also thought it would help the teacher ambassadors. They are the ones that bring the student ambassadors to the Tech School and the leadership program. It also gives them a bit of leverage for future endeavours. (Tech School student ambassador coordinator)

The impact on teacher learning was enhanced when Tech Schools and secondary schools collaborated more fully to develop programs with mutual benefits:

> We know that two of our partner schools are completely revamping their curriculum style. They have not got there fully yet, but they are in the process which is fabulous. We ran a full day professional development program for 70 of their teachers who really want to work together and the feedback from the teachers is that they really want to but they're not sure how to sometimes. So, we are part of a long-term process of trying to help with that transition which can be tricky if they don't have the infrastructure, in terms of timetabling and how students are examined. (Tech School educator)
>
> It is about collective buy-in. In that way, we are not doing things for schools, we are doing things with schools. What we are seeing now, is schools that are taking this model of education are building maker-spaces in their own schools and they are starting to see the value of the model for "PD-ing" all of their teachers, not just their STEM teachers. (Tech School director)

An ideal situation discussed by teachers and Tech School educators would be to connect units of work at school with the Tech School programs:

> I think our aspirational state for the Tech School programs is that they become embedded into the schools' curriculum with visits at key points of the design process. It might be a focus on prototyping for example or it might be a presentation's focus and the Tech School enables you to be more immersive in the process. There might be an immersive ideas sprint with time to develop things back at school and design your prototype, then come back to manufacture. (Tech School director)
>
> That project around sustainable housing: the students in Year 7 do sustainability and these types of topics. Now that could be explicitly taught here and the students could do that research as part of a unit of work and developing prototypes of sustainable houses. Then, heading to the Tech School for that real specialised use of technology and having access to the expertise of

> these guys in the use of software and laser cutting. (Music and humanities teacher)

Yet, the logistics of providing a Tech School experience to all students was noted as an issue:

> I think with the Tech School, it is easy to do it with a small group of kids. You can target 10 kids from year 7, 8 or 9 and take them up there to work on a project. That is easy. But the challenge is that we have 250 Year 7 kids who are all working through a sustainability project. Because we want it to be equitable. We want all these kids to have access to it and have their eyes open to the types of manufacturing, the types of software, the types of thinking processes and design processes that they are going to need. (Music and humanities teacher)
>
> At the moment I still see us as an excursion place. Is that going to have an impact on a child's life? Probably not, because it is so fleeting. Whereas, I know that some schools are trying to embed it more. Thinking of this as an extra campus or a wing of some school. It's like something that everybody wants. But logistically it is kind of a nightmare to do that. But that is what everyone wants. So, we just need to make it happen. (Tech School educator)

To make this transition, reengaging senior school management was seen as necessary for greater Tech School impact:

> I see our effectiveness as being much higher, if we were able to get greater buy-in from schools. I think there is a need for a bit of reengagement around visiting principals or deputies. Having engagements or breakfasts for principals and deputy principals to get them excited about what we are doing here. (Tech School director)
>
> I think that it will be a slow process because we have a lot of partner schools and teachers that will come through programs. But I think the impact of looking at STEM education in a different way will be huge over time. And I think that looking at problems, not as discrete subjects but from a multidisciplinary angle, the way that we work in life. (Tech School educator)
>
> I think the biggest thing is the purpose of the Tech School. I know it is an evolving thing that they are working through in terms of what works and what doesn't. What are the fundamental skills which are good for students to have? (Music and humanities teacher)

Establishing direct relationships between schools and industries was considered to be a central role of Tech Schools:

> The Tech School will have an impact if it shows the array of possibilities within that pathway. So, the Tech School has a big job from the political side, if it is to show the kids the different areas that they can end up by going through a STEM pathway. And that is where they are going to have an impact. (Mathematics teacher)
>
> The important thing is that we give young people insights into pathways into industry so that they can understand that this is a viable community for a career and that they don't have to move away to find opportunities. They just need to be aware of what they have here. It is really important for schools to understand that they have a role to create aspiration for students through industry engagement too. There is nothing stopping them from adopting our model and bringing in an expert to talk to kids. (Tech School director)

Finally, one impactful idea for Tech School support discussed, was the development of inter-institutional learning networks:

> I would love to see a STEAM teachers' network or a teachers' network as well as one like a community of practice that has industry and education. I would love an education-based focus and an industry-based one. (Interdisciplinary learning leader)
>
> I think that one good thing that the Tech School does is have a very good network. So, it is a good place to sit and reach out, and position myself as a STEAM leader at the school. (STEM teacher)

Emerging Insights from Case Study 4.

The organisation of the results into subheadings reflects the key themes which emerged from the interviews. Key themes in relation to mediating factor 1 – project-based learning in schools, included: more time needed by teachers to plan, implement and assess projects; different meanings of STEAM and how to teach it; and the importance of having enthusiastic and capable teachers for running interdisciplinary projects. While interviewed teachers were enthusiastic about running STEAM projects in school, the *structural constraints* related to timetabling and assessment were seen as major impediments, especially if projects were run across subjects.

Regarding mediating factor 2 –types of supports provided by Tech Schools currently for teachers, two themes stood out: *programs* designed by Tech Schools and *professional learning* (PL) for teachers. Overall, Tech Schools provided unique opportunities regarding technologies and program implementation which complemented subject-based learning in schools and served as useful content for PL. Yet, without *integrating the projects into schools* the Tech School impact was minimal, resulting in some disengagement from school leaders.

Mediating factor 3 considered how Tech Schools could have a deeper impact on education with stakeholder comments organised under one theme: the need to develop a multistakeholder *interinstitutional learning community* (ILC) where teachers, students, industry and community members could collaboratively design and implement authentic projects in schools. The role of Tech Schools in mediating such an ILC is the major theme informing the analysis of case studies 3 and 4 in Chapter 6 and the conclusion in Chapter 7.

Through the organisation of data into key themes, some primary analysis has already been undertaken. This primary analysis will be elaborated through the use of Analytical Framework 2 to critically evaluate tensions and synergies from these results in Chapter 6.

Chapter Conclusion

The results presented through four case studies have been included to demonstrate the range of activities undertaken by Tech Schools as mediating organisations. Case study 1 provided a rigorous approach to evaluating two Tech School programs by triangulating data from a standardised evaluation, surveys and interviews to highlight Tech School pedagogies. Case study 2 presented a vignette of a secondary school STEAM festival with a focus on the design thinking process as a structure, as well as the potential for increasing connections to the mandated curriculum. Case study 3 focussed on the role of Tech Schools in mediating between industry and education through authentic project-based competitions and co-designing programs with industry. Case study 4 provided insights from the main stakeholders in the Tech School initiative: teachers, students, industry leaders, Tech School educators and directors.

While the multiple case study design may suggest a breadth over depth approach to research, this approach can be justified for the following reasons:

1. Tech Schools are an emerging phenomenon, with this research study being one of the first studies undertaken. For this reason, outlining the main activities of Tech Schools will allow for *key areas to be further researched*. Each of the four case studies represents an area worthy of more in-depth research in future.
2. As Tech Schools undertake many activities in supporting schools and educational change more broadly, it was unclear which area would be of most significance and most worthy of research. Providing *an overview of the multiple Tech School activities* has provided insights into how these activities are interrelated. For example, the co-design process with industry connects to Tech School programs and pedagogies, which connects to their integration into secondary schools and the types of PL needed. These activities are part of a cycle of change involving a redesign of education. Understanding the *process as a whole* allows for deeper insights than studying any single aspect in isolation.

This chapter has presented results with some primary analysis. Chapter 6 will provide deeper analysis of tensions within each of the activities and across the activities. Cross-case analysis using the analytical frameworks provides some generalisable findings and key themes which are transferrable to new educational contexts. Chapter 7 will expand the focus of discussion from the local case studies of Tech Schools as mediating contexts for *school support*, to the broader political and theoretical implications of Tech Schools as mediating contexts for *educational change*.

Chapter 6: Analysis

Introduction

The findings from four case studies in chapter 5 are analysed using analytical frameworks 1 and 2. Case study themes are synthesised to develop generalisable insights into the integration of STEAM programs in secondary schools using Tech Schools as mediating organisations. Theoretical insights are connected to the empirical findings from the case studies to generate concrete tools for teachers and curriculum leaders in schools. The process of case study analysis and synthesis is now outlined.

- Case study 1: evaluations of both Tech School programs are synthesised into a table with pedagogical insights for implementing project-based learning (Appendix D2)
- Case study 1: secondary analysis using Analytical Framework 1 to compare and contrast the two programs as a sequence through three layers of pedagogy
- Case study 2: secondary analysis using Analytical Framework 1 to compare pedagogies in the school STEAM festival and the programs from case study 1
- Case studies 3 and 4: common themes are synthesised using Analytical Framework 2 to outline how stakeholders can collaboratively implement projects
- Synthesis of analyses as a strategic plan for deepening the impact of Tech Schools through the alignment and coordination of stakeholder activities.

These stages of analysis connect the data to the research sub-questions. Through analysis and synthesis of case study findings, the notion of Tech Schools as mediating organisations for supporting project integration in schools is expanded through a plan for coordinated actions by all stakeholders as part of an inter-institutional learning community (ILC). This answers the central research question from a local perspective. Chapter 7 goes beyond the local impact of Tech Schools, in predicting future developments for the Tech School initiative.

Synthesis of Evaluations in Case Study 1.

Preliminary analysis was undertaken in chapter 5 for the purpose of triangulating participant interviews, survey data and standard criteria for evaluation. Further analysis of case study 1 is undertaken to generalise the findings to support Tech Schools and secondary schools plan, implement and evaluate STEAM programs. Prior to this analysis using Analytical Framework 1, the evaluations of two Tech School programs from case study 1 were synthesised into a table (program1: tourism showcase and program 2: poverty inquiry). The table is included in the appendices as Appendix D2: Synthesis of program evaluation.

General findings from synthesising examples of success and recommendations have been included in column 3 of the table in Appendix D2. These generalised findings represent empirical data organised according to criteria from constructivist theories of learning. For school teachers and Tech School educators these generalised findings could serve as a valuable guide to successfully planning and implementing STEAM programs.

Secondary Analysis of Case Study 1

For the purpose of this thesis an additional layer of analysis is provided to consider why different aspects of the two programs were successful or unsuccessful as well as how these aspects related to the overall delivery of the 3-day programs. This is done through the use of Analytical Framework 1. Following this secondary analysis, final recommendations for STEAM program design and pedagogies will be provided. Figure 7, a modified version of Analytical Framework 1 is used for this secondary analysis of data.

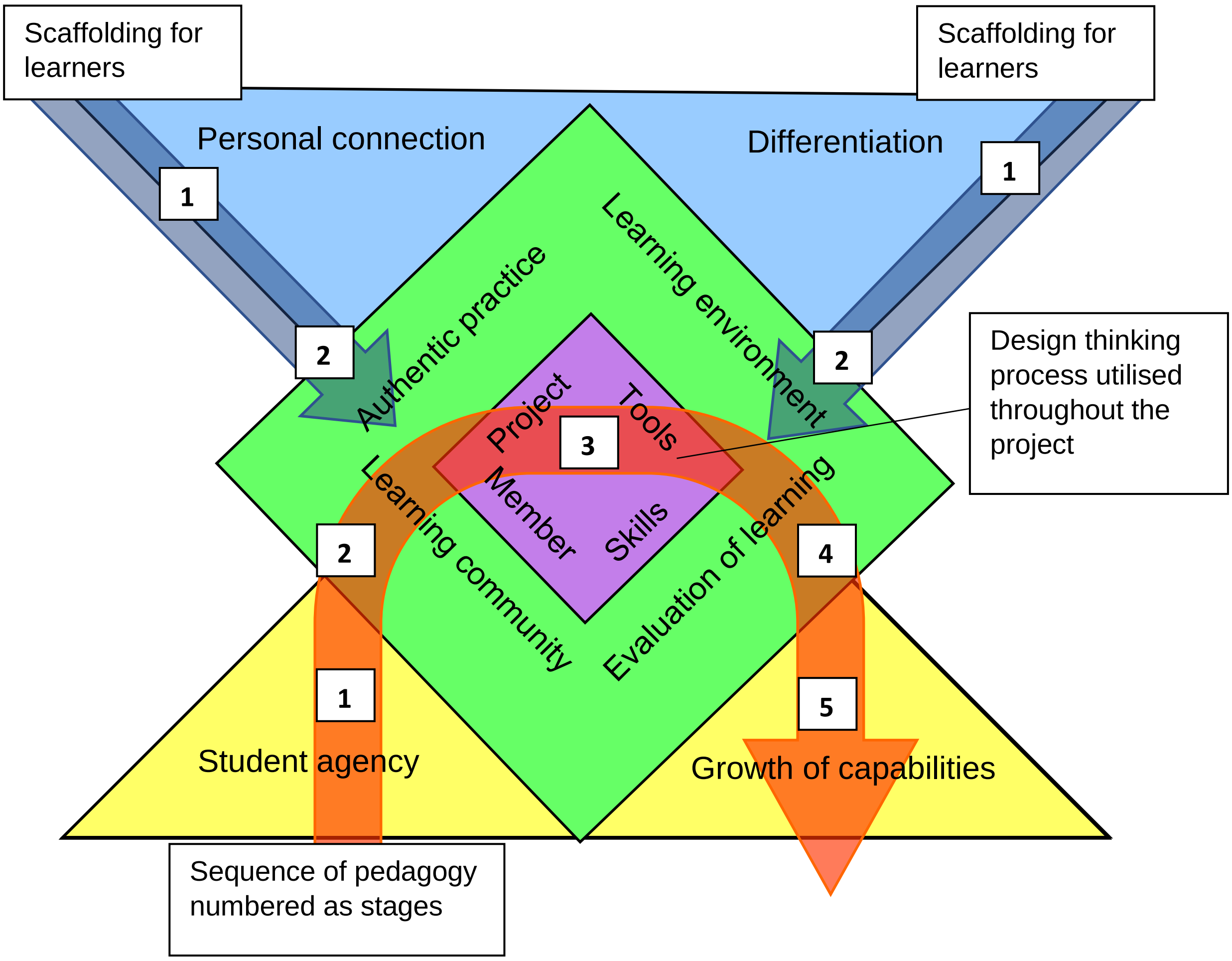


Figure 7. General sequence of Tech School programs through layers of pedagogy.

The difference between this diagram and Analytical Framework 1 is the addition of arrows which represent the sequence of learning and teaching observed in the Tech School programs and the main areas of focus for educators supporting this learning. This was signposted in Chapter 3 as an abstract conception of a learning and teaching progression for Tech School programs. It will now be fleshed out with findings from Appendix D2 to compare the two programs. Sequence steps (1-5) are included in brackets. Key terms from the framework are italicised.

Stage 1- Personal layer:

The starting point for Tech School programs is fostering *student agency* (1) and building a *personal connection* (1) between students, the Tech School educators and the program topic. Program 2 (poverty inquiry) was better integrated with school learning than program 1 (tourism showcase) because Tech School 2 sent out a booklet with pre-work to be completed in-school before attending the Tech School program. This meant that the students had an understanding of the purpose of the

Tech School, what the project would be about and had done some preliminary research into the issue of poverty and vulnerable members of the community. This preliminary work meant that students in program 2 started with an *existing motive for learning*, whereas this motive had to be developed over the course of program 1 (Mariane Hedegaard et al., 2012).

Both programs provided opportunities for student agency such as experimenting with new technologies, yet, program 1 focussed more on developing specific types of student capabilities such as critical and creative thinking about the topic. This is an example of backwards design of the program by considering the end-point of the program – the *growth of student capabilities (5)* and aligning pedagogy accordingly. Program 2 provided more supports than program 1 for students with different needs, including visual organisers and short workshops on technology. Both programs could have provided simple trouble shooting guides for independent problem-solving with technology and encouraged students to share their goals and plans to increase autonomy of learning and agency.

To summarise the different pedagogical strengths of the programs for individual learning: program 1 emphasised student *growth of capabilities (5)* and *student agency (1)*, while program 2 emphasised building *personal connections (1)* and *differentiating learning (1)*.

Stage 2- Lesson layer:

Both programs invested time in developing a *learning community* (2) through the use of design thinking process and terminology as well as *authentic practices (2)*. Program 1 was especially strong in using conferences, informal student presentations and reflections throughout the program which encouraged students to share their work and consolidate learning as a class. Program 2 made use of different teachers' expertise and team teaching, which demonstrated professional adult collaboration. It also provided some variety in teaching which was lacking in program 1.

The use of distinctive Tech School features such as a green screen room in program 1 and a makerspace in program 2 allowed for the *learning environment (2)* to be used a pedagogical resource. The difference in the types of prototypes being produced meant students in program 2 engaged in more hands-on construction with carboard, sensors, 3D printing and laser cutting than the AR prototype in program 1. Yet, program 1 made good use of the digital affordances of Tech Schools as new learning environments to create the AR app, record video and use media editing software. Program 2 had shorter explanations, demonstrations and lectures than program 1 which allowed for more active student learning. Program 1 made use of other student groups to test the students' prototypes which was an outstanding demonstration of peer learning (2). This social dimension to the Tech School situates their pedagogical approach firmly within Vygotsky's (1978) and Dewey's (1964) theories of constructivism.

Overall, program 1 has been identified in the standard evaluation as providing more opportunities for relational learning through lesson structures, yet, also having more issues in terms of relying too much on a single presenter and long explanations which reduced student engagement.

Stage 3- Project layer:

Both programs followed the design thinking process to structure the project. For this reason, the pedagogies are fairly similar between programs, yet, they are different from traditional school pedagogies. Large touch screens were excellent examples in program 1 of using technology for collaboration and interactive learning. The use of *tools to enhance learning (3)* such as a booklet for the school outlining the program, design thinking process, assessment links and possible classroom activities is an outstanding example of scaffolding by program 2. This is an example of using secondary mediating artefacts to orientate students and teachers to the practices and norms of a Tech School program (Wartofsky, 1979, pp. 200-201). Having short technology workshops in 3D print design and laser cutting on day 2 of program 2 were excellent ways of *upskilling* (3) students at their point of need. This program also resulted in high quality prototypes being made with 3D printers and laser cutters. Because much of the empathy and define stages were covered in school, more time was available for prototyping, resulting in better student products. This makes a case for embedding part of the Tech School projects in schools.

Overall, scaffolding team work was important in both programs and is essential for successful project management by students as *team members* (3). As mentioned previously, more problem-solving tools and strategies would have helped students independently manage the project, which can be embedded in each stage of the design thinking process (Plattner & Institute of Design at Stanford). One area where both Tech School programs need some attention is, making explicit *links between the project and STEAM careers* (3). According to Baxter (2017), this is fundamental to raising the level of career aspiration and shifting professional stereotypes. Career links could include examples of STEAM professions that would develop similar solutions using the design thinking process. Similarly making *links* *between the project and school-based learning* (3) could be enhanced by drawing on specific subject content from the humanities, science and technologies.

Stage 4- Lesson layer:

After the students had finished working on their projects, the joint focus of the educators and students was on *evaluating the student prototypes* (4) and their use of the design process. This involved the students pitching their solutions in the Tech School to their school teacher, other student groups and the Tech School educator. For programs 1 and 2, the students prepared a script and PowerPoint slides addressing each of the stages of design and a brief explanation of their prototypes. The student presentations were an excellent summation of new skills developed by the students in technology, design and project management. Yet, in both cases this was a missed opportunity for school assessment which is an impediment to integrating STEAM projects in schools (MacDonald et al., 2019). The presentations could be a major piece of *summative assessment* (4) if connected to a unit of work at school. Program 1 included time for students to write a group reflection on their learning. This was absent in program 2 due to a lack of time. As with the pitch presentations, this reflective writing could contribute to school assessment of learning in one or more subjects (refer to Appendix E for curriculum connections).

Stage 5- Personal layer:

In completing the full cycle of learning through layers of pedagogy, the end-point of the program and the main of Object of learning is the *growth of capabilities* (5) which are transferrable to new contexts and other projects. Program 2 seemed to be further along with the process of connecting the programs to local industries and the visiting schools. The Tech School for program 2 has a foyer for displaying student work and selected examples are presented to local industries. The connection between the project, the visiting schools and local industries is predicted to be an area that Tech Schools will become more active in mediating. This might involve facilitating presentations in schools and online, as well as introducing the schools to industry mentors for direct collaboration to allow some students to continue developing their prototyped solutions.

Summary of Case study 1 Secondary Analysis.

General findings of successful project-based STEAM program design and pedagogies were provided by synthesising triangulated data within a constructivist framework for evaluation. This contributes to answering research sub-question 1 regarding how Tech Schools engage students. It also provides some pedagogical guidelines to support teachers to implement transdisciplinary STEAM programs, which relates to sub-question 2. As a guide for school teachers, this comparative analysis of two Tech School programs has a *pragmatic application.* The analysis also has a *theoretical application* related to the types of skills and capabilities promoted in Tech School programs which reflect the political nature of the Tech School initiative.

Pragmatic application of comparative evaluations.

The analysis of case study 1 benefits Tech School program designers and Tech School educators in considering how they might *evaluate their pedagogies and programs*. It contributes to Tech School research in providing a *method for collecting and analysing data* on programs for comparative evaluations. Finally, the generalised findings in Appendix D2 are transferrable to a school environment for teachers wishing to design and implement successful STEAM programs based on the Tech School model of design thinking. This adds to existing frameworks in STEAM and STEM by C. Quigley et al. (2017); Chu et al. (2019) and Bybee (2015).

Analytical framework 1 was used to consider how the two Tech School programs compared in their pedagogical strengths and weaknesses. It provided a means of relating specific *pedagogical actions* to *stages of a project-based program*. This could benefit Tech School program designers, Tech School educators and school teachers in considering the overall flow of a program and key pedagogical aspects which fit within stages of program delivery.

Theoretical applications of comparative evaluations.

Synthesis and comparative analysis, highlighted the overall focus of the programs, which supports some generalisations of the educational culture of each Tech School.

Program 1 emphasised the growth of capabilities, student agency and authentic practices which reflect a political focus on *employability and entrepreneurial skills* as part of a Tech School culture focussed on the *outcomes of education*. This perspective is supported by the *Soft Skills for Business Success* study by Deloitte Access Economics (2017) as a key educational policy-shaping document.

Program 2 emphasised personal connections, differentiation and the learning environment which reflect a political focus on *personal learning pathways* in education as part of a Tech School culture focussed on the *processes of education*. This perspective is indicative of educational recommendations in the *Through Growth to Achievement* report by the Department of Education and Training (2018).

This analytical generalisation supports a clearer understanding of the relationship between pedagogy and politics through educational culture. In this way, the research on Tech School programs builds on critical theories of education outlined in Chapter 2 (Freire, 1996; Giroux, 2001). Confirming the generalisation would require more program evaluations from each Tech School as well as further triangulation focussed on the *pedagogical beliefs* of the Tech School educators, program designers and the director in fostering a distinct educational culture. This exceeds the scope of the case study analysis.

The findings from case study 1 are now compared to case study 2 findings through *cross-case analysis*. This will be followed by a similar process of cross-case analysis of case studies 3 and 4.

Cross-Case Analysis of Case Studies 1 and 2

Summary of case study 2 findings.

Case study 2 presented an example of a STEAM festival run in a school using the design thinking process, followed by some recommendations for making links to the mandated curriculum and to industry which are supported with resources in Appendix E (unit plan) and the full journal article in Appendix G. The main findings from case study 2 were:

1. The STEAM festival provided students with *agency* in what problem they were trying to solve and how they would create their prototype. For teachers, the *authenticity of the project* was valued as well as the opportunity to work across disciplines. Students and teachers appreciated the social and collaborative nature of the STEAM festival, yet there were *issues in relating the projects to assessable outcomes from the curriculum*.

2. Embedding STEAM projects into the school timetable could provide meaningful learning experiences for students with *authentic connections to the curriculum and the world* outside of school.

3. The full article (Appendix G) outlined how Tech Schools can support the process of integrating projects into schools by providing:

- the environment for producing a more high-tech prototype, following the first design iteration at school
- rubrics with explicit curriculum links for their programs
- mediated contact between schools and industries

Secondary analysis of case study 2 will utilise Analytical Framework 1 to compare the 4-day STEAM festival with the 3-Day Tech School programs from case study 1. As the presentation of the results for case study 2 was in the form of a journal article rather than the standard evaluation used in case study 1, direct comparison is limited. Yet, Analytical Framework 1 is adaptable to different forms of data collection, which will be demonstrated through cross-case analysis of case studies 1 and 2.

To compare the STEAM festival to the Tech School programs, the same program stages are used as for analysis of case study 1, although key words from the framework are used as headings for this cross-case analysis rather than the sequence of stages.

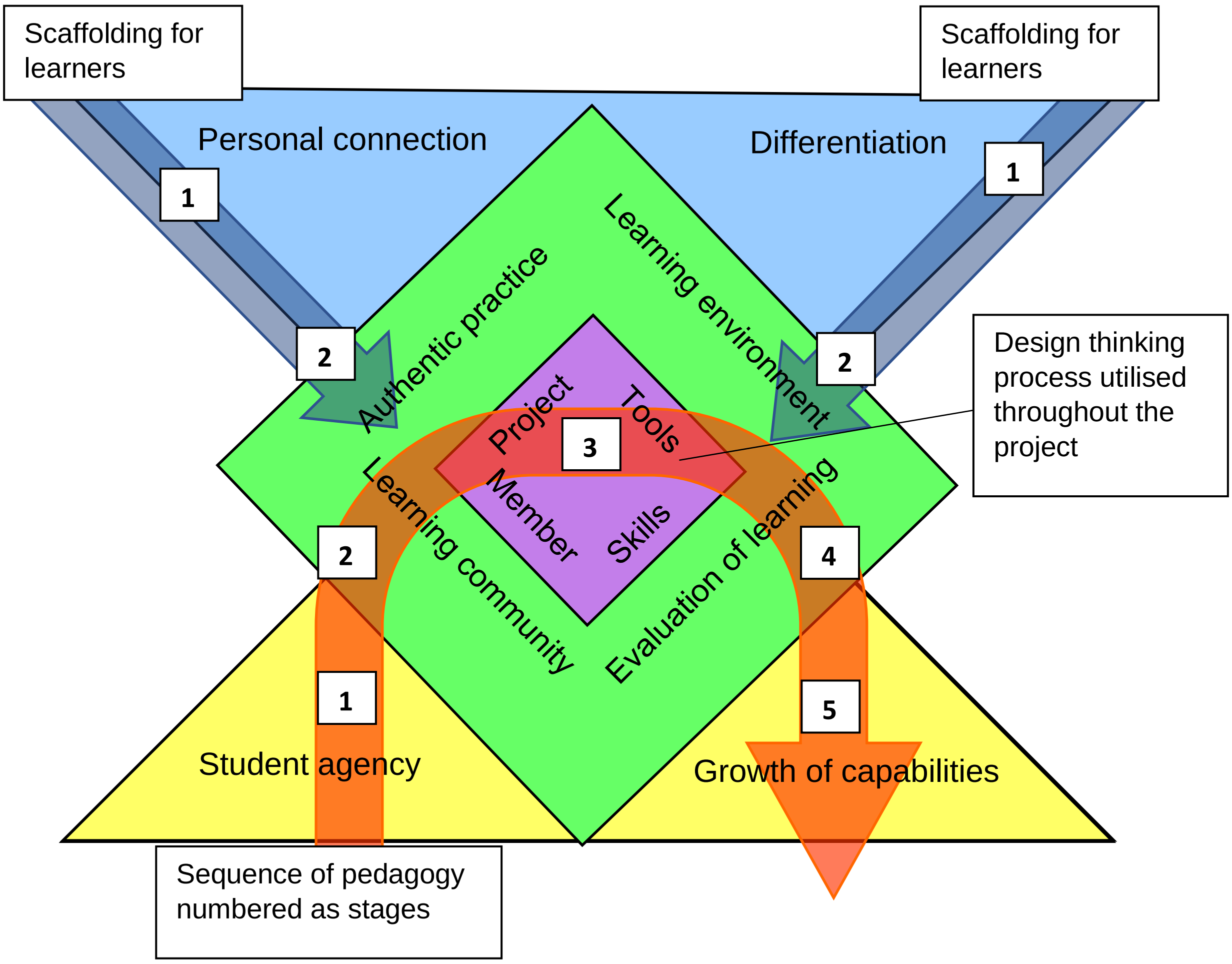


Figure 8. Sequence of Tech School programs through layers of pedagogy.

3-day Tech School Programs and 4-day School STEAM Festival Compared.

Personal layer.

Personal connection (1): The school STEAM festival had existing *personal connections* between students and teachers, which was lacking in the Tech School programs. Yet, Tech School 1 created a stronger connection to the *program topic* by asking schools to complete pre-work on the design thinking process and an exploration of the issue to be solved. This lack of integration between school learning and the STEAM festival topic was noted by teachers in the secondary school. Prior to the festival, teachers could have prepared students for the housing project by reviewing design thinking and researching issues related to the topic.

Differentiation (1): Because the school teachers knew their students well in the school STEAM festival, they differentiated instruction more successfully based on *individual student need*. The school teachers were able to motivate disengaged and challenging students. Yet, they lacked expert knowledge of the design thinking process and new technologies. This meant that the students in the STEAM festival did not develop the same level of technology skills or design thinking experience. For this reason, the Tech School programs differentiated instruction more successfully based on *different levels of technology skills*. The Tech School educators were able to extend students who had high levels of skill and motivation. This reflects a tension in interdisciplinary teaching between *content knowledge* – especially with regards to science, mathematics and technology – and *pedagogical content knowledge* which requires contextualising content to meet the needs of specific students (Berlin & White, 2012; Ertmer, 2014; Frykholm & Glasson, 2005; Shulman, 2013).

Student agency (1): The school STEAM festival provided more opportunities for student agency in terms of freedom, while the Tech School provided more opportunities for skill development. Students in the festival were able to choose their topics such as housing, tourism or agriculture. Because the STEAM festival was in the last week of school, there was a high level of fun and social bonding with greater freedom in how the students worked and what work they produced than in the Tech School programs. The interviewed students in school appreciated this *personal and social freedom*. Yet, the Tech Schools provided more opportunities for students to learn new skills and manage their projects, which resulted in the construction of prototypes that better addressed the users' needs with more sophisticated use of technology. Thus, the school festival offered more *personal and social freedom*, while the Tech School programs offered more opportunities for *personal extension and professional development* of skills.

Growth of capabilities (5): The Tech School provided more opportunities for *student growth* of capabilities in design and technology, yet, the school STEAM festival provided more opportunities for *teacher growth* of capabilities. This reflects the different types of impact that Tech Schools can have. The in-house Tech School programs delivered high-quality *packaged* learning experiences for students which have a *short-term impact* on growth of capabilities. The school STEAM festival *embedded* the Tech School programs, requiring teachers to collaboratively plan and implement projects with students which has a *long-term impact* on growth of capabilities (Thomas & Huffman, 2020a). As discussed in the results section, an ideal model would involve teachers integrating projects into schools as term units resulting in a *whole school growth* of capabilities, with a visit to the Tech School for *specialised growth* of technological capabilities.

Lesson layer.

Authentic practice (2): The school STEAM festival reflected more authentic workplace and industry practices than the usual timetabled, subject-based model of traditional schooling. Yet, the Tech School provided many more authentic practices than the STEAM festival. Some of these practices were related to the use of technology such as green screens, laser cutters and 3D printers. Yet, many of the authentic work practices utilised in Tech Schools could be translated to school environments. These included: up-skilling workshops; conferences; formal and informal student group presentations; and reflections. For each stage of the design thinking process the Tech Schools provided more sophisticated scaffolds to relate the student experience to industry practices. Exceptions to this were the secondary school's use of a guest speaker from a homelessness support organisation and an excursion to a Tiny House construction industry. This demonstrated that schools can make use of *real industry experiences* for authentic practices, which is a limitation of Tech Schools. In contrast, Tech Schools can provide advice, training and resources to schools to help them build *authentic industry practices* in-school.

Learning environment (2): Tech Schools are model examples of innovative learning environments (ILE). The opportunity for using state-of-the-art technologies is the reason why Tech Schools have been built. As noted in the results for case study 2, the technological limitations of the school STEAM festival could be overcome by organising an excursion to the Tech School at the prototyping stage to maximise the *technological affordances* of Tech Schools. Yet, as noted in case study 4, this is not sustainable as Tech Schools cannot accommodate all students from all schools. For this reason, many schools are building makerspaces with a range of high and low-tech technologies. Tech Schools could provide advice on how to develop technological makerspace learning environments. One key insight from the literature is that a change to school culture is needed as many technologies are only utilised by design and technology teachers, rather than *integrating technologies* into all subject areas. This integration across disciplines would raise the general level of technological self-efficacy amongst all teachers (Ertmer, 2014; L. M. Harasim, 2012; Herro & Quigley, 2017).

Learning community (2): The STEAM festival developed a stronger learning community than the Tech School programs. This was, to some degree, because the students and teachers knew each other in the school. Yet, the school teachers created many opportunities for building *social bonds* between students and teachers such as: going on an excursion; having different year levels participating in the festival; serving breakfast to students; displaying student projects for parents to see during parent teacher interviews; collaborative planning; team teaching and peer reflection by teachers. These are examples of the ways that schools can maximise on their capacity to build *learning communities* to engage students in projects. As discussed in Chapter 7, Tech Schools could help to expand the school learning community to include local industries and community groups through the development *of inter-institutional learning communities* (ILCs).

Evaluation of learning (4): As noted in case study 1 analysis and case study 2 results, evaluation of learning is an area that could be improved in the Tech School programs and the school STEAM festival. Both Tech School B (poverty inquiry) and the secondary school created a booklet for students to complete which was informally assessed by the teachers, yet the assessment did not contribute to school recording. *Connecting project-based learning to the Victorian Curriculum* is an argument that has been made throughout this thesis. Through discussion and collaboration between this study's researcher and one Tech School, curriculum alignment is now a standard feature of programs and *curriculum aligned rubrics* are included in Tech School design challenges (refer to Appendix F). Appendix E is an example of how schools could also connect school projects to the curriculum through interdisciplinary term-long units.

Project layer.

Project (3): The STEAM festival and Tech School programs had been developed with input from industry. The school STEAM festival created a strong connection to local community groups and industries using a guest speaker and an excursion. This could be enhanced by sharing student prototypes with industry groups. The Tech School programs lacked this visible connection with local industries. Yet, Tech School B, invites local industries to view high-quality student work. In this way, secondary schools could use industry for *student engagement in the initial stage* of the project and the Tech School could use *industry feedback in the final stages* of the project.

Tools (3): The Tech School programs provided state-of-the-art technologies for student prototyping which could not be matched by the secondary school STEAM festival. Yet, the school teachers found low-tech solutions which were engaging for students. The use of *hands-on materials* such as: clay; cardboard; paint; popsicle sticks and hot glue provided tactile, embodied experiences which were lacking in Tech School A's AR program. This supports the argument that the arts are vital in providing embodied and aesthetic experiences through diverse media (Eisner, 2002). Tech School B seemed to have the perfect balance between craft materials and digital technologies with 3D printed and laser-cut features incorporated into painted cardboard prototypes.

Member (3): The poverty inquiry and sustainable housing projects had a stronger *social cause* than the tourism program by encouraging students to act as members invested in a collective venture. The equal distribution of labour between students was a more significant issue in the school STEAM festival with some students not contributing and the attendance rate dropping after the first day. The Tech School programs were able to maintain student commitment to the project by investing time to help the students select and work in specific roles which created *interdependence* between team members.

Skills (3): Both the school STEAM festival and the Tech School programs helped students develop diverse skills including: research; time management; problem solving; oral presentation and reflection. This is a strength of the *solutions-focussed project model* based on the expectation that students in groups will produce a tangible outcome from their learning (A. Diefenthaler et al., 2017). As noted in the case study interviews with teachers and supported by the literature, this is mostly absent from mainstream subject-based learning, with assessment focussed on knowledge recall through exams (Lucas et al., 2013; Wagner & Dintersmith, 2015). In comparison, the Tech School programs fostered specific skills in *technology* as well as *project management* skills, while the STEAM festival fostered skills in *independent problem solving* and *creative design*. Ethical and critical thinking, as well as experimental testing are aspects of the Tech School programs and the festival which could be enhanced by exploring the issues in more depth in specific subjects.

Summary of Case Study 2 Secondary Analysis.

Case study 2 was an example of how one secondary school integrated a Tech School program into their school. This was largely due to the commitment of teachers who had undertaken professional learning in Tech School workshops and wanted to *transfer STEAM programs to their own environment*. It reflects a deeper impact on the school system than the PL workshops, or the Tech School programs alone. A comparison between the 3-day Tech School programs and the school STEAM festival revealed strengths and limitations in both contexts. It is hypothesised that having an integrated school unit followed by a three-day visit to a Tech School would *maximise the affordances of both context*s and overcome the limitations of each. The challenge of integrating projects across subjects in schools was a theme which emerged from the results of case studies 2 and 4.

Following-on from these case studies, the researcher worked with one Tech School to create resources to support secondary schools develop interdisciplinary project-based units. These resources include: a *unit planner* (Appendix E) and *generic STEAM rubrics* (Appendix F). These resources, in addition to case study 2, contribute to answering sub-question 2 of the thesis: How can Tech Schools support teachers plan, teach and evaluate STEAM projects?

Case studies 3 and 4 are now analysed to examine how social learning scaffolds can be developed by Tech Schools to support a structural change to secondary schooling. This is followed by a comparison of all case studies at the end of Chapter 6 and their conceptual synthesis in Chapter 7 Conclusion.

Secondary Analysis and Synthesis of Case Studies 3 and 4

The findings from case study 3 demonstrated the benefit of Tech Schools in mediating engagement between industry and secondary schooling through the co-design of programs and competitions. Limitations to this engagement were also discussed in relation to embedding the programs in schools. The findings from case study 4 presented opportunities and challenges of STEAM program design in secondary schools and the role of Tech Schools as mediating organisations. To begin the analysis, the findings for both case studies will be outlined. For the purpose of comparison, case study 3 is broken into its separate examples: industry-Tech School competitions and co-design of programs. Numbering is used for reference in the analysis and in Chapter 7.

Summary of case study 3 findings.

3. 1) Thales design competition:

- *Opportunity for project authenticity*: Personal connection by students to real issues in the community
- *Opportunity for student agency*: Students decided the issue to solve and managed the project with support from teachers and their Tech School
- *Opportunity for industry support*: Industry mentorship provided at school and the Tech School
- *Challenge of group cohesion*: Students working outside of school hours and having to leave subjects in school hours, made group work difficult
- *Lack of school support*: Teachers were not aware of the competition
- *No school reporting*: Learning outcomes were not assessed against subject-specific curriculum
- Recommendation to embed the competition into an integrated unit

3.2) Program co-design with industry:

- *Authentic industry issues*: Generated by local industry representatives
- *Awareness of project-based learning*: Opportunity for industries to experience Tech School project-based learning and provide feedback
- *Opportunity for collaboration*: Industry leaders networked and shared insights from their fields
- *Building school-industry relationship*: Potential for sharing student prototypes with participating industries as designed solutions to their industry issues
- *Challenge of time*: A single session for co-designing was quite short (rushed)
- *Co-design lacked school presence*: Missed opportunity for industry representatives to have discussions with education representatives

General finding: Industry competitions and co-design of education programs with industry add authenticity to learning, yet it takes time to plan and implement these activities. Tech Schools can support this process by acting as a broker or mediator between local industries and schools wanting to engage in industry-school projects.

Case study 4 findings: Summary from the three subheadings.

4.1) Perceptions of interdisciplinary project-based STEAM in secondary schools.

Obstacles:

- Timetabling of separate subjects in set blocks of time limits interdisciplinary projects

- Teaching to cover a rigid curriculum is not engaging for students or relevant to the workplace
- Project-based learning needs to be assessable and reported to parents
- Some teachers lack skills in STEAM program design and new technologies which affects their confidence and enthusiasm
- Teachers need to be supported by school leadership and adopt a whole school approach

Opportunities:

- Teacher collaboration across arts, humanities, science, technology and mathematics in planning, implementing and assessing learning
- Assessment of curriculum capabilities relevant to real-world issues
- Broad themes that span topics in different subjects help students to make connections between concepts
- Coordinating project-based units could be facilitated by interdisciplinary STEAM leaders

4.2) Support provided by Tech Schools for teachers undertaking project-based STEAM units.

Enablers:

- Programs in Tech Schools provide examples of running STEAM programs and project-based pedagogies
- Tech Schools allow access to high-tech equipment and three days of immersive learning at the facility
- Some Tech Schools have prepared booklets that can be used in schools prior to attending a Tech School program as well as rubrics for curriculum assessment
- Professional development for teachers on design thinking and technologies
- Tech School Programs accessible online and free digital resources available

Limitations:

- Lack of personal connections to students and their different needs
- Some Tech School educators lack experience in subject-based teaching and school pedagogies
- Tech School programs are not specifically connected to individual schools' environments, cultures or learning programs

4.3) Building a networked community of learning to support longer-term structural changes needed for STEAM integration in schools.

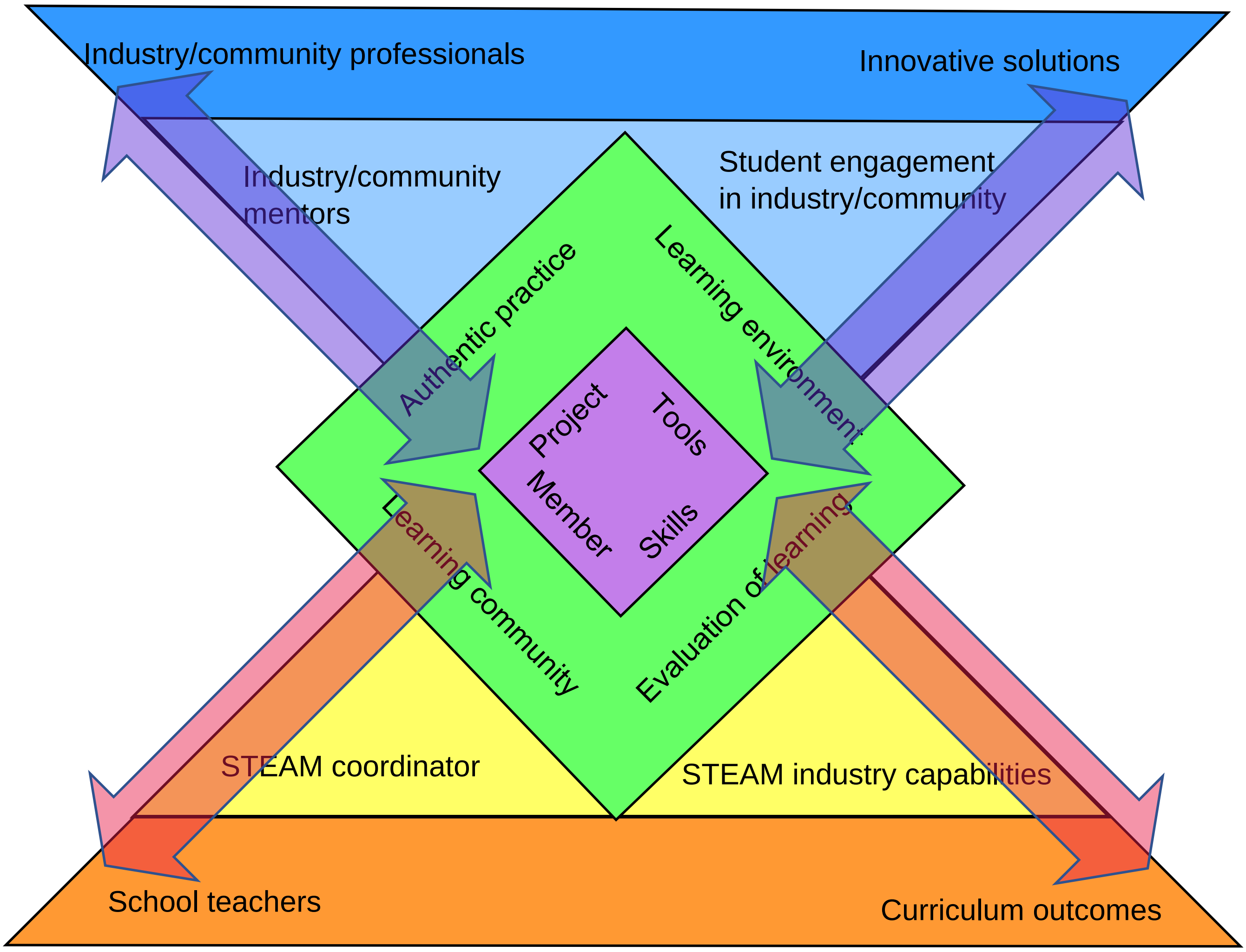
Opportunities:

- Student ambassadors have a leadership role in transferring skills from their Tech School
- Running innovation workshops with teachers who want to shift school structures for project-based learning as well as a network of teachers and industry representatives with an interest in STEAM projects
- Professional advice on how to set up a school makerspace
- Developing tailored support for schools, with Tech Schools adapting program delivery based on the requirements of school projects
- Reengaging school principals and leadership in embedding authentic industry and community projects into school structures
- Building stronger connections between local STEAM businesses and schools

General finding: For Tech Schools to have an impact on school-based STEAM programs, a more unified approach is needed. This could involve the further development of a network of stakeholders such as an ILC with a common vision and the development of new roles in schools and industry. These roles would be focussed on making changes to school structures such as: flexible timetabling; project learning being assessed on curriculum content and the application of skills for real industry and community issues; industries providing mentorship; and Tech Schools becoming more adaptable to the needs of schools.

Synthesis of case study 3 and 4 findings: What was and what could be.

The general findings from both case studies have a similar theme related to deepening the impact of Tech Schools by expanding their mediating activities through a networked community of learning focussed on partnering schools with industry and community groups through authentic projects. This common theme will be examined using Analytical Framework 2, shown in Figure 9.



Key

Organisation	Key roles
School	School teachers
	STEAM coordinator/student ambassadors
Tech School	Tech School staff
	Project developer
Industry/community organisations	Industry/community mentors
	Industry/community professionals

Figure 9. Tech Schools mediating school-industry relationships.

Framework for Analysis, Synthesis and Extension of Case Studies 3 & 4.

Reviewing the framework.

Analytical Framework 2 has been reproduced here with the addition of arrows representing the relationship between stakeholders from industry and schools on the left and the relationship between their aims or motives on the right. Key terms from the framework are italicised in this analysis and numbering refers to the summary of findings for case studies 3 and 4.

Analytical Framework 2 shares similar features to Analytical Framework 1 in its structure, consisting of two overlapping/interpenetrating triangles of activity mediated by a Tech School. In both frameworks the outer layers represent personal motives for the activity or the "personal layer" of activity. While in Analytical Framework 1 this represented personal motives of individual students and teachers, in Analytical Framework 2 this represents the institutional motives of school teachers and industry/community professionals in their respective environments (shown in dark blue and orange). The green diamond represents the Tech School as a mediating organisation in relating the activities of industry and school through engagement with *industry mentors*, *STEAM school coordinators* and *student ambassadors*.

It is this "relational layer" of activity that could serve as an inter-institutional learning community (ILC), in which industry mentors provide insights into *authentic practices* and a *learning environment* related to industry. STEAM school coordinators provide insights on the development of a *learning community* and the *evaluation of learning*. The purple diamond in the centre represents the "project layer" of activity which may be a school unit, an industry competition or a Tech School program. The findings from the case studies will now be analysed in relation to these three layers of activity: (i) The *project layer* of collective activity; (ii) the *relational layer* of an inter-institutional learning community; (iii) the *personal layer* of meeting specific needs and opportunities of industry and schools as key stakeholders. New roles emerging from this interactivity will also be discussed as well as the relationship between activities across layers as indicated by the arrows.

(i) Project layer: Collective activity.

Case study 3 explained the role of industry in Tech School competitions and the co-design of programs. In considering the purpose for the projects, the focus was on building student interest in new STEAM industries by emphasising technological *tools*, such as sensors in the Thales competition (case study 3.1). From the perspective of promoting authentic relationships between schools and industry/community, there potentially could have been more input from schools in this process as well as community groups as *members* invested in the projects. For example, by involving student ambassadors in the process of determining issues that they felt passionately about which may not be industry issues (case study 4.3). Teachers might have suggested focus areas from the curriculum that would benefit from a project-based approach to learning such as the cross-curriculum priorities: Australia's engagement with Asia; Sustainability; and Aboriginal and Torres Strait Islander histories and cultures (Australian Curriculum and Assessment Reporting Authority, 2020). Having *projects* that reflect industry focus areas, local community issues, meaningful topics for students and priority areas from the curriculum would allow all stakeholders to benefit from the projects selected.

This requires regular consultation from each of the stakeholders to achieve a synthesis of political and educational aims (case study 4.3). In mediating this consulting and planning process, Tech Schools could develop research committees with student and teacher ambassadors, community and industry collecting data on their representative groups and then co-designing programs collectively. This would be an authentic means of developing *skills* in using *data for educational programming* which extends the current Victorian DET's focus on *data for student assessment* (https://www.education.vic.gov.au/school/teachers/teachingresources/practice/Pages/insight-data.aspx). It would also reframe the co-design process from: (a) Tech Schools mediating a *sequence* from industry to teachers and then students (Case study 3.2), to (b) collective and *ongoing consultation* between stakeholders. In this way, stakeholders not only design student projects, but they are themselves *members* of a collective project: building an ILC to use projects for development in industry, community and education.

From a theoretical perspective the ILC creates the conditions for building "relational expertise" across professions (Anne Edwards, 2011, p. 32). Largely, this is an expansion of current Tech School activities. Yet, it promotes a more integrated and ongoing process of stakeholder involvement which includes teachers as co-developers of a culture of learning. This is reflective of Giroux's (2001) and Freire's (1998) theories of radical pedagogy whereby teachers are "cultural workers".

(ii) Relational layer: Inter-institutional learning community.

Developing and maintaining an *inter-institutional learning community* (ILC) as a collective project deepens the notion of teacher professional learning from: (a) design and technology skills, to (b) having expert knowledge in curriculum, community issues, networking, program design and policy change. This extends the

Victorian DET's current initiative of professional learning communities (PLCs) which is part of the FISO framework of teacher practice (https://www.education.vic.gov.au/school/teachers/management/improvement/plc/Pages/default.aspx). Whereas a PLC is focussed on fostering collaborations between teachers in schools – which is an *intra-institutional* community, an ILC would be focussed on fostering collaborations between schools, industry and community – which is an *inter-institutional* community. This requires new skills, new roles and new platforms of engagement between stakeholders in schools, industry and community groups which could be mediated through a Tech School.

As no single teacher, industry representative or Tech School educator can have this depth and breadth of expertise, the ILC would require formalising emerging roles such as "industry mentors" (case study 3.1) who could work closely with schools and Tech Schools to design, implement and *evaluate* authentic projects that have ongoing support for students and build engagement and aspiration in local industry and community issues. "Student ambassadors" (case study 4.3) could have more input into school programming and Tech School programming, in becoming activists for social change. "Teacher ambassadors" upskilled in design thinking pedagogies and program design (case study 1) could work with school "interdisciplinary leaders" (case study 4. 3) to plan units that authentically address curriculum requirements to support the development of STEAM industry capabilities (case study 2). These new roles are examples of Etienne Wenger's "boundary spanners" who broker between different communities through "boundary objects" in the form of cross-disciplinary projects (2000, pp. 235-236).

Finally, Tech Schools could shift their staffing focus to work more closely with industry mentors, student ambassadors, teacher ambassadors and interdisciplinary leaders which is an example of mediation as an *authentically collaborative practice*. Through research, consultations and planning meetings, Tech School educators could become "inter-institutional learning consultants". Finally, the notion of a "mediating organisation" could expand beyond Tech Schools to become "mediating institutions" with distinct departments in schools, community groups and industry. Presently, Tech Schools have begun the process of collective change as mediating organisations, yet the formalisation of an ILC as a "mediating institution" is only a prediction.

(iii) Personal layer: Specific needs of school and industry contexts.

For collective action to be adopted by individuals in their own contexts of professional practice, individual motives need to be considered (Daniels, 2012). For industry, paying for the time that *industry mentors* invest in education programs needs to have value. Immediate gains for local industries include: idea-sharing with other industries, community groups and schools as part of a network; industry-promotion by publicly supporting schools and students; and the possibility of having students generate *innovative solutions* to their problems. Long term gains include encouraging local school students to become involved in participating industries which can lead to employment as well as having an impact on the education system (case study 3.2).

For schools, value includes mentorship and support from industry, and authentic projects for students that deliver *curriculum outcomes*. Yet, a recurring theme in case studies 3 and 4 was the need for alignment of motives and a common vision across the schools studied. Examples of a lack of common motives were: students not receiving support from teachers for their projects (case study 3.1); teachers having trouble finding time to plan and teach interdisciplinary units (case study 4.1); teachers struggling with leadership to make structural changes including separate subjects and the timetable (case study 4.3); and interdisciplinary leaders finding that teachers lacked *STEAM capabilities* and confidence (case study 4.3). This was also noted in the literature on teachers and schools transitioning to interdisciplinary STEAM, but lacking a collectively agreed approach (MacDonald et al., 2019; Thomas & Huffman, 2020b)

It can be inferred that the issues highlighted in the case studies come from an *absence of an aligned vision* which includes a subjective and objective aspect. Subjective: in relating social tensions between individuals. Objective: in having different professional motives related to maintaining or disrupting the school status quo. It seems that alignment across layers is needed for impact in schools and industries. This is shown with the double headed arrows in Figure 9. The alignment of actions between stakeholders with key roles and actions is presented in Table 8 as a strategic plan for coordinated integration of projects in schools using an ILC. Colour coding matches Analytical Framework 2.

Table 8

Relating Industry and Schooling Through an ILC

LAYERS OF ACTIVITY	KEY ROLES	ACTIONS IN CONTEXT
Project layer: Collective learning and input	Industry/community mentors for educational projects	Research issues and ideas in their own organisations through surveys and meetings to present in co-design workshops.
	Tech School head of programs and projects development staff	Collates issues and ideas collected in schools and industries, and chairs the co-design workshops.
	School interdisciplinary learning leaders, STEAM teacher ambassadors and student ambassadors	Research issues and ideas in their own schools through surveys and meetings with students and teachers.
Interinstitutional community layer: Relational learning and expertise	Industry/community mentors for educational projects Tech School director, head of programs and projects development staff School principals and interdisciplinary learning leaders, STEAM teacher ambassadors and student ambassadors	Co-design process includes: the design of specific programs and projects from research in school and industry/community context; mediation between participating organisations; and providing specific support such as resources and communication. Co-design also includes strategic plans to engage education with industry and community through subject-integrated project-based learning.
Personal layer: Industry/ community organisation context	Tech School projects development staff	Liaise between participating industry/community organisations and schools on specific projects through organisation mentors.
	Industry/community mentors for educational projects	Coordinate the involvement of the organisations including scheduling, development of resources for the projects, and feedback on student prototypes.
	Industry/community professionals	Communicate new issues and opportunities in the organisation to the mentors for educational projects.
Personal layer: School context	Tech School projects development staff	Liaise between participating schools and industry/community organisations on specific projects through ambassadors and interdisciplinary leaders. Provide resources and in-school PL.
	Interdisciplinary learning leaders, STEAM teacher ambassadors and student ambassadors	Communicate and plan projects with domain leaders and teachers to address issues related to timetabling and curriculum.
	School domain leaders and teachers	Collaborate with interdisciplinary learning leaders to plan, implement and assess projects integrated into subjects.

Table 8 is a synthesis of the findings from case studies 3 and 4 organised within the layers of activity from Analytical Framework 2. It demonstrates how reorientating Tech School mediating activities towards expanding the ILC to align motives within and between industry/community organisations and schools could further the impact of project-based learning in schools. This would address issues brought up in the case study findings such as: a lack of support for STEAM ambassador teachers (case study 4.1) and for students participating in STEAM competitions (case study 3.1); insufficient Tech School support within the school context (case study 4.2); disengagement with projects by school leadership (case study 4.3); a greater need for student agency and involvement in program design (case study 3.2); more authentic industry presence in education (case study 3.2) and a more collaborative co-design process of projects involving all stakeholders (case study 3.2).

Highlighting these issues is not intended to be a criticism of Tech School mediating activities which have until now been in early stages of development. This can be termed a "stage 1: Introduction phase" of impact focussed on: delivering programs in the facility; designing engaging projects for students in schools; and building a relationship between local industries and schools. Tech Schools can be seen as now entering a "stage 2: Partnership phase" of mediation through the development of specific resources for teachers in schools. Yet, as the analysis of case studies 3 and 4 demonstrate, Tech Schools could have a greater impact by supporting schools to integrate project-based learning into their school structures. This will require a "stage 3: Community phase" of mediation through coordinated structural change which should be a collective effort involving all relevant stakeholders. This represents a *radical reform* to school education which is discussed in literature on educational innovations by Zhao (2012b); A. Diefenthaler et al. (2017) and Serdyukov (2017). Table 8 presented a plan for a "stage 3 impact" of Tech School mediation between schools and industry through an expansive ILC with new professional roles dedicated to integrating community/industry projects in schools.

Summarising All Case Studies: Key Insights from the Cross-case Analysis

For case study 1, Analytical framework 1 was used to compare and contrast two Tech School programs within three layers of pedagogy. Examples from both programs were synthesised under key themes to serve as a guide for successful project-based pedagogies. This addressed sub-questions 1 and 2 of the research study.

For case study 2, findings were compared to case study 1 through Analytical Framework 1 to identify how a school-based STEAM project can be connected to a Tech School program. Specific tools for teachers running integrated STEAM units were developed (refer to Appendices E and F). These include a unit plan and an example of curriculum aligned rubrics developed by the author in collaboration with a Tech School. This addressed sub-questions 2 and 4 of the research study.

For case studies 3 and 4, Analytical framework 2 was used to consider how Tech Schools could have a deeper impact on education through the development of an interinstitutional learning community (ILC) with formally defined roles and activities for stakeholders across layers of activity. This addressed sub-questions 3 and 4 of the research study.

The dialectical frameworks for projects presented in this thesis apply across three levels of education: first through the *interrelationship between teaching and learning* in project-based pedagogy. Second through *interdisciplinary programming* in project-based STEAM units. Third through *inter-institutional learning communities* in community-industry-school projects. Tech Schools could have an integral role in mediating across all three layers of educational reform.

Synthesis of Analyses.

A final synthesis of all cases study analyses is provided as a table. Table 9 integrates the cross-case analysis of the case studies to respond to the central research question:

How can Tech Schools as mediating organisations promote student, teacher and school engagement in authentic STEAM projects?

The table is a matrix consisting of columns representing the depth of impact that Tech Schools can have in aligning the needs of stakeholders involved in STEAM projects between layers of activity from individual *activism,* to social *activity* and collective *actions*. The rows of the table represent the breadth of impact that Tech Schools can have by coordinating between stakeholders. Chapter 7 will elaborate the empirical findings to answer the research question and sub-questions by drawing upon relevant literature reviewed in Chapter 2 for discussion.

Table 9

Tech School Impacts on Project-Based Education Through Layers and Contexts of Mediation

Aligning Tech School mediation	**Layers of Tech School mediation for change**	**Students**	**Teachers**	**Interdisciplinary School Leaders**	**Industry/community Leaders**
Alignment of Tech School *layers of mediation* to support personal, relational and collective goals	**Individual activism: Personal motives** Supporting individual plans, goals and agency	Agency to engage with community and industry through projects and to authentically engage in projects at school	Authority to design and implement authentic learning experiences with diverse modes of assessment	Flexible school structures which adapt to innovations in education and meet curriculum requirements	Opportunities to be involved in education by promoting new developments and issues in industry and community
	Social activities: Relational capabilities Networked community of learning with development of relational expertise and identity	Students become ambassadors for change by sharing issues and new ideas from their perspectives	Space in the timetable to collaborate, experiment with new pedagogies and explore interdisciplinary project/program designs	Collaboration between interdisciplinary leadership and domain leaders to plan units with connections to industry/community themes and curriculum	Industry/community mentors working with schools as part of an ILC and collaborating in community-industry-education projects
	Collective Actions: skills for change Tools, resources, PL, policies and research to implement system changes	Development of skills in technology, project design, leadership and communication with leaders external to school	Professional online learning as well as access to low and high technologies through a makerspace and resource loans from the Tech School	Tech Schools provide frameworks, project-based program co-design sessions, contacts to industry and expert advice	Ongoing involvement with schools to co-design programs, plan design challenges, competitions and publicly showcase partnerships with schools
	Examples of Tech School mediation for each stakeholder	-Ambassador leadership program -Involvement in community events -Role in school project-based ILC -Community challenges and industry competitions -Public platforms for presenting/communicating	-Role in project-based ILC -Workshops on program design and pedagogy -Online resources -Consultation on makerspace setup -Curriculum aligned rubrics -Mobile Tech School -Tech School provides tailored educational services	-School co-design workshops with leadership and teachers -Brokering between local industries and schools -Research on schools using project-based learning structures -Curriculum aligned frameworks	-Industry co-design workshops -Industry/community competitions and challenges -Industry incursions and excursions with schools -Sharing of research, design and innovations -Ongoing support for students with innovative projects
	Coordinating Tech School mediation	***Coordination*** of Tech School *context of mediation* to allow communication and collaboration between stakeholders in schools and with community and industry			

Stage 2 and 3 impacts of Tech Schools as mediating organisations.

Table 9 organises the main findings from the four cases into three layers of impact by key stakeholders involved in project-based learning in schools. The layers of impact are derived from the *personal, relational* and *collective* layers of pedagogy in Analytical Framework 1 and equivalent layers of inter-institutional activity from Analytical Framework 2.

In this table, the first row "individual activism" reflects the personal perspectives shared by stakeholders during interviews on their motives and goals related to project-based learning. This was an increase in: *agency* of learning for students (case study 3.1), *authority* for teachers to experiment with project-based pedagogies (case study 1), *flexibility* in school structures for interdisciplinary leaders (case study 4.1) and *involvement* by industry and community in education (case study 4.3). Student agency, teacher authority and structural flexibility challenge the reified system of schooling which has created institutional codes, roles and frames to counter individual activism (Bernstein, 1973). Tech Schools can have a mediating role by *differentiating their support* based on the needs of individual stakeholders and *advocating for structural changes* to enable project-based practices. Activism requires radically changing perceptions of practice which are grounded in the daily routines and beliefs of individual participants in school and work (Giroux, 2001). Tech Schools as advocates for ground-level activism can positively disrupt the bureaucratic status quo of school, reified in the physical structures of classrooms, timetabling and subject silos (Fullan et al., 2018).

"Social activities" in the second row emphasises the use of a network to coordinate project-based learning in schools which was the focus of table 8: inter-institutional learning community (ILC). The key theme from interviews with stakeholders was a need for allocated space, time and roles for *collaboration* (case studies 3 and 4). This was also a theme within the literature, with teachers needing "pedagogic space" to design interdisciplinary programs as part of communities of practice (Aslam et al., 2018, p. 66). Tech Schools can mediate this collaboration by coordinating space and time for stakeholders with roles within the ILC and the context of their own practices.

The third row "collective actions" – and third layer of Tech School mediation – requires the provision of necessary resources and training to support the implementation of integrated community-industry projects in schools. Observations, surveys and interviews highlighted the need for students to develop *project skills* such as technology and leadership; and for teachers to have access to a suitable online and physical *pedagogical environment* (case study 1). Participant interviews indicate that this requires interdisciplinary school leaders to establish a method to integrate projects (case study 4.2), and for industry/community organisations to have authentic input into education (case study 3.2). This organisation of collective actions is dependent on middle management in schools opening channels between the classroom and community/industry allowing for institutional innovation (Serdyukov, 2017). Tech Schools as mediating organisations for system level change, may need to focus their energies on upgrading schools' "leadership from the middle" (Fullan, 2015).

Examples of the types of support currently provided by Tech Schools for stakeholders as well as potential supports are included in the fourth row. Yet, there are limitations in the level of impact that Tech Schools are having as mediating organisations. This is due to two reasons which are highlighted in the table and emerged from analysis of the case study findings:

1. For each of the stakeholders studied, examples of a *lack of alignment* between their motivations, collaborative activities and collective actions was noticeable. For example, some teachers were motivated to design integrated projects but lacked skills, space, time and authority to act on their motive for educational activism (case study 4.1). In contrast, alignment of *activism* to solve a community problem, *activity* in a design challenge and *action* in developing new skills resulted in impactful learning for a select group of students participating in the Thales competition (case study 3.1). By aligning activism, activity and action – shown as columns in the table – stakeholder influence on education can be more impactful. Tech Schools could increasingly *differentiate their support* for different stakeholders by targeting the specific impediments to innovation across layers of impact (Serdyukov, 2017). The scaffolds developed by Tech Schools for students used in the Thales competition, are also needed for teachers to achieve meaningful changes to practice.

2. For each of the layers of impact, *issues of coordination* were noted in the case studies. For example, the lack of communication and of goals between students, some teachers and leadership involved in the Thales competition (case study 3.1) or between teachers attempting to develop an interdisciplinary unit and their school leaders (case study 4.1). Without a whole-school approach involving concrete tools like STEAM frameworks and social networks with industry and community, teacher

PL doesn't necessarily translate to school-level impact (Herro & Quigley, 2017; Thomas & Huffman, 2020a). Tech Schools could increasingly mediate *communication* between stakeholders, *coordination* of collaborative activities and *distribution* of training and resources.

Chapter Conclusion

Secondary cross-case analysis of the case study findings demonstrated that Tech Schools can mediate the integration of projects in schools, yet isolated innovations such as industry competitions and STEAM festivals lack impact. They are either inauthentically assimilated into the existing paradigm of schooling or they are conveniently pushed into the background of business as usual for schools (Serdyukov, 2017; Thomas & Huffman, 2020a). *Alignment and coordination* across layers and contexts of the Tech School initiative are recommended next steps to pool resources, enthusiasm and expertise from a broad range of stakeholders and to mediate their efforts to *embed project-based learning in schools*. Tables 8 and 9 serve as strategic plans for fully utilising the personal, relational and collective affordances developed by the Tech School initiative to innovate the school system through alignment and coordination of stakeholder involvement.

Beyond strategic plans, teachers and leadership in schools require tangible resources for *reorientating structures* such as the timetable, subjects and the curriculum to accommodate project-based learning (C. Quigley et al., 2017; Zhao, 2012b). Interviews with teachers revealed that proposing a complete paradigm change by modifying all these structures was unrealistic (at this stage) as schools have a responsibility to prepare students based on external standards and to cover the curriculum. For this reason, resources were developed for teachers to design interdisciplinary projects *within existing school structures* (Appendices E and F). The *unit plan* (Appendix E) divides a project into blocks that can be taught in different subjects. The *rubrics* (Appendix F) align Tech School projects with the Victorian Curriculum. These resources represent the assimilation of projects within schools as an intermediate step towards structural accommodations supporting project-based learning. Case study analysis has emphasised how Tech Schools in the short term can *enhance* existing structures in schools rather than abolishing them. Recommended changes to school structures are reserved for Chapter 7.

The case study analysis utilised two analytical frameworks to consider Tech Schools as mediating contexts:

- Analytical Framework 1: Project-based pedagogies and program design with curriculum connections.
- Analytical Framework 2: Inter-institutional relations between schools and industry/community organisations involving new professional roles.

Both mediating activities of Tech Schools were synthesised in Table 9 to encapsulate the impact of Tech Schools at a *local level*. Yet, Tech Schools could also have an impact on the *political context of education*, as well as future research in education. These themes were established in the literature review by evaluating the role of education relative to societal and industrial development. This sociological lens will be utilised in the final chapter of this thesis, Chapter 7 Conclusion.

Chapter 7: Conclusion

Introduction

This chapter commences with a final summary of key insights from the cross-case analysis. While the research sub-questions were addressed through analysis, these questions will be answered by connecting key ideas from the literature to the case study analyses. The development of Tech Schools as mediating organisations for increased impact on education through structural changes was presented as occurring in stages. These stages, structure the discussion of findings.

The overall structure of this chapter is the reverse of the literature review. The literature review was divided into two sections with an overview of the relationship between educational, social and industrial developments in the 4IR, as well as a critique of the STEM initiative in section 1. This was followed by an outline of the specific types of impacts that Tech Schools can have on education in section 2. In this chapter, part 1 is focussed on specific impacts to answer the research sub-questions and the research question at a local level. Part 2 of the conclusion is focussed on situating the findings from the research study on Tech Schools within the broad landscape of educational politics to evaluate how education as a system can best prepare students for the opportunities and challenges of the 4IR.

The central research question will be answered through these two parts of the chapter. First, Tech Schools as mediating organisations for the promotion of *stakeholder engagement in authentic STEAM projects* at a local level. Second, Tech Schools as mediating organisations for *changing the structures of schooling and the education system* more broadly.

The conclusion to this chapter demonstrates that overcoming limitations to Tech Schools as local mediating organisations (part 1 of the research question answer) requires Tech Schools to engage more directly in mediating changes to school structures and education more broadly (part 2 of the research question answer). The conceptual framework and four stage model (figure 10) of structural change are utilised to make recommendations to further the impact of Tech Schools as mediating organisations for integrating STEAM in schools.

Part 1: The Local Context

Reviewing Research Sub-Questions: Comparison Between Analysis and Literature.

The four research sub-questions for the research study were:

1. How do Tech School programs and pedagogies promote student engagement and growth of capabilities in STEAM?
2. How do Tech Schools support the development of new teacher pedagogies related to planning, teaching and evaluating STEAM projects?
3. How do Tech Schools mediate the relationship between schools, industry and community?
4. What are the enablers and constraints of embedding the Tech School model of STEAM learning in secondary schools?

These four research sub-questions informed the case studies selected for the research study. Each question will be answered in two parts: (1) findings from analysis and (2) reference to the literature.

Sub-Question 1 addressed through case study 1: Tech School programs.

This case study provided a comparison between two Tech School programs with an emphasis on project-based pedagogies and program design. Primary analysis revealed that excursions to the Tech School provided an example of quality constructivist pedagogies which were engaging for students. Yet, cross-case analysis revealed that teachers found it hard to apply Tech School projects in their own schools due to constraints such as the timetable, reporting against the curriculum, subject silos and a lack of resources. This was a common theme discussed by the participants. It is also reflected in the literature on the challenges of implementing STEAM in schools by Thomas and Huffman (2020a). Tech School 3-day programs were categorised as "stage 1" impacts of Tech Schools as mediating organisations with *low-level commitment from schools* and *low-level disruption to schools* as they consisted of excursions to the facility.

Secondary comparative analysis using Analytical Framework 1 generated common themes regarding project-based pedagogies and the sequencing of the program through layers of pedagogy. Key theories from constructivism were utilised in developing the analytical framework for evaluating project-based pedagogies (Section 2, part 2 of the literature review). The empirical findings support this method of evaluation for two reasons:

First, it provided insights into different types of pedagogical interactions between educators and learners in working through a project. The key difference between this pedagogical approach and traditional pedagogies used in mainstream secondary Australian schools was that learning and teaching became *dialectically interrelated through layers for personal, social and collective learning*. In this way pedagogy was an application of social psychology to prepare learners for the multiple roles they will undertake as professionals and members of diverse social groups (Brewer & Sedikides, 2001).

Key insight: Reviving constructivist pedagogy through rigorous evaluation.

The teacher-learner interactions differed throughout the program depending on the educator's *pedagogical intentions related to the stage of the program*. These included building a personal connection between the students' individual motives, the educator's background and the project theme for personal learning; building a learning community which utilised the environment and authentic practices for social learning; and focussing on project skills and team membership for collective learning. These empirical findings support the notion that constructivism as a pedagogical paradigm can be nuanced and rigorously evaluated. The analytical framework also allowed for a synthesis of different types of constructivism such as personal constructivism focussed on individual growth (Dewey, 1902/1971; J Piaget, 1970), social constructivism focussed on intersubjective relationships (J. S Bruner, 1996; L. Vygotsky, 1978) and critical constructivism focussed on collective activity (Freire, 1985; Leont'ev, 1978; Mead, 1934). These theorists are summarised in Table 3, Chapter 2 of the thesis. Analytical framework 1 and the standard evaluation criteria provided a consistent method for defining, implementing and evaluating constructivist pedagogies in project-based programs.

Second, the *structure of the program played a significant pedagogical role*. This meant that less direct teaching was needed as the students learned skills and capabilities through their participation in the program. Having templates, exemplars and trouble-shooting guides for problem solving in technology and the design thinking process were shown to be essential to scaffold independent student learning through each stage of the program.

Overall, in the Tech Schools, students had an active role in learning through their involvement in programs that fostered a sense of agency, autonomy and purpose. It represented a return to Dewey's classic theories of progressive education concerning democratic and experiential learning (Dewey, 1916/2010, 1938/1997). Engagement in learning became authentic as student activism was promoted through a structured process of design (A Diefenthaler et al., 2017).

This case study demonstrated that constructivist theory in high-tech learning environments is an area of ongoing importance in education to ensure that technology supports the full development of the learner (L. M. Harasim, 2012). These Tech School projects also reflected a pedagogical shift for teachers from explicit teaching of curriculum content *to reflexively responding to the needs of students respective to the requirements of the project stage*. This was explored further through case study 2.

Sub-Question 2 addressed through case study 2: Four-day STEAM festival.

This case study provided an example of the Tech School design thinking model used to structure a transdisciplinary project in a school. Cross-case analysis revealed that the design thinking process was effective in making *authentic connections between school and real-world community issues*. The projects supported a high level of *agency and autonomy of learning* for students and a *collaborative, cross-disciplinary pedagogical approach* by teachers (A. Diefenthaler et al., 2017; Stith & Geesa, 2020). Yet, the lack of curriculum-aligned assessment in transdisciplinary projects was a sticking point for teachers who wanted to embed STEAM in their school, yet, needed to report against the curriculum (MacDonald et al., 2019). This issue was noted in interview comments from case study 2 and case study 4 as teachers struggled to incorporate projects into existing school structures such as timetabling, separate subjects and reporting against the mandated curriculum.

Key insight: School-based professional learning for teachers.

These case study findings informed the design of a STEAM unit planner (Appendix E) and the collaborative development of a generic STEAM rubric aligned to the Victorian Curriculum for levels 5-10 (Appendix F). Subsequent to this research, Tech School professional learning workshops are increasingly becoming focussed on supporting teachers to plan, implement and assess STEAM projects *in their own school context.* This reflects the literature on professional development (PD) compared to professional learning (PL), where support for teachers should be *embedded in their daily teaching practice within a community of learners* rather than through external PD workshops (Bissaker, 2016; Fullan, 2007; Thornton & Cherrington, 2019). The provision of resources and PD workshops for teachers by Tech Schools was categorised as part of the current "stage 2" impact of Tech Schools in supporting teacher and student ambassadors which could become a “stage 3” impact through the development of an ILC (outlined in Chapter 6).

Analytical Framework 1 was used for secondary analysis to compare pedagogies in case studies 1 and 2. This identified that Tech Schools could support teachers to build from their strengths in fostering student agency and personal connections related to personal student learning, by extending student learning in project management and technology skills, prototyping and sharing work with industry and community which are relevant to collective team learning. By utilising Tech Schools at key points in STEAM programs – such as the later stages of projects – teachers could maximise the pedagogical support offered by Tech Schools.

Sub-Question 3 addressed through case study 3: STEAM industry competitions and co-design.

This case study provided two examples of school-industry engagement: designing authentic industry-based programs and incorporating them into schools through design competitions.

Example 1: An industry competition, provided authentic learning in design and technology for the participating students with *real-world outcomes through prototyping solutions to community problems*. This provided the students with an experience of a solutions-design industry in their local community, which Baxter (2017) notes is integral to the aspirational role of secondary schooling. Yet, the impact was limited by the small number of participating students and a lack of awareness from non-participating teachers in the school. This created tensions in terms of *offering equal opportunity to all students* – not just a STEM elective group. From a critical constructivist perspective, STEM electives could *increase* the technology skills-divide, as it is the students who are least likely to be in a STEM class who may benefit most from developing skills in new technologies. As STEM education and professions are attracting more financial rewards in Australia (Karp, 2020, 19 June), the skills gap could lead to social inequality after the completion of secondary schooling through less employment opportunities for “non-STEM” graduates (Office of the Chief Scientist, 2016a, p. 30).

Embedding industry design competitions into units of work across multiple subjects for all students in a year level would provide an equal opportunity for all students to participate. As discussed in interviews from case study 4, this creates logistical issues for schools – especially if they want to access the Tech School facility – without making changes to structures such as timetabling. Cross-case analysis of case studies 1-4 informed the development of a proposed interdisciplinary unit to support school teachers and leaders overcome the constraints of timetabling and utilise different services offered by Tech Schools such as making contact with relevant local industries (Appendix E).

Example 2: Co-designing with industry, provided real-world issues to inform the theme of the programs and for collaboration between industry representatives. The structured co-design process increased the authenticity of the learning programs, although it didn't address the issue of supporting schools to collaborate with industries directly. According to the Australian Industry Group (2017) this is a significant challenge for schools. Tech Schools could *mediate partnerships* between schools and industries, which is a recommendation from the literature on using broker organisations (Australian Industry Group, 2017; Education Services Australia, 2018).

Key insight: Authentic school-industry partnerships through an ILC.

Secondary analysis of case studies 3 and 4, proposed the development of an inter-institutional learning community (ILC) focussed on integrating industry/community projects in schools. ILCs are a growing field of organisational research as industries increasingly collaborate on projects with diverse stakeholders (Dille & Söderlund, 2011). *Helping schools and industries build common knowledge and expertise* also reflects theories of inter-professional learning by Anne Edwards (2011), and Wenger-Trayner and Wenger-Trayner (2014). The development of a strategically utilised ILC would represent a "stage 3" impact and signify a turning point in education by partly shifting subject-based curriculum delivery to an interdisciplinary model. Using an ILC as a *stage 3 impact* would provide schools with significant support to make necessary structural changes which Zhao (2013) has labelled the "paradigm shift" in education. Tables 14 and 15 represent strategic plans for Tech Schools as mediating organisations to facilitate radical changes to school structures enabling integration of interdisciplinary project-based learning. Having a well-articulated plan as well as a community of invested members is essential for making the shift from *supporting t*he school status quo to *positively disrupting it* (Lucas et al., 2013).

By opening-up schools to community and industry, resources and mentoring could become available to teachers and students with minimal outlay of time or money as Tech Schools might lever funding and staff. It would also extend the current education focus on professional learning communities (PLCs) to better prepare teachers for education *beyond the school environment* https://www.education.vic.gov.au/school/teachers/management/improvement/plc/Pages/default.aspx. This would address the road blocks to school innovation discussed by Serdyukov (2017). One recommendation from the research study is that an ILC should be integrated into schools and industries through the creation of formal roles such as *industry mentors*, *STEAM ambassadors* and *interdisciplinary leaders*. While these roles exist informally, an ILC might require the creation of *formal job positions* in Tech Schools, secondary schools and industries to design and integrate projects in schools with *explicit goals for value-adding* for local schools, industry and the community through projects.

Sub-Question 4 addressed by case study 4: interviews with stakeholders on integrating STEAM in schools.

The participant interview responses confirmed the need for Tech Schools to move beyond stage 1 and stage 2 mediation by actively supporting schools to make changes to their structure of curriculum delivery. The development of an ILC as a *stage 3 impact* was an emergent theme as well as using Tech Schools to lever change in education towards interdisciplinary curriculum delivery. This level of activism by Tech Schools represents a *transition from the local context to the political context of mediation*. It is proposed that this represents a "stage 4" development of Tech Schools as mediating organisations. This is predicted to involve the further expansion of the network for project-based learning in schools through collaboration with other institutions and organisations across Australia and internationally advocating for a "paradigm shift" in education (Zhao, 2013).

Key insight: From projects in schools to schooling through community projects.

Stage 3 Tech School mediation, has been described as a "tipping point" for school-based projects as it would involve disruptions to school structures as well as commitment to project-based learning by school management and leadership. It would also involve opening-up secondary schooling to a range of organisations typically seen as distinct from education such as local industry, community groups and Tech Schools. Analytical Framework 2 was used to examine the multiple layers of interactivity between schools and industry. Analysis revealed how the boundary between the institution of schooling and other institutions became permeable as school teachers, Tech School educators and community/industry representatives adopted roles – such as STEAM "ambassadors" and "mentors" – that spanned all three contexts. As Etienne Wenger (2000) notes, it is at the boundaries between communities that the greatest opportunities for learning through synergy occur, as well as the greatest challenges, due to the ambiguity of identity and potential for misunderstandings. Table 8 presented the distinct activities of different stakeholders in a Tech School mediated ILC to effectively bridge the school-industry divide through projects.

Interviews with key stakeholders in Tech School programs and school-based STEAM revealed that stage 3 mediation is needed to overcome the structural constraints of timetabling, subject silos and to achieve cultural change in schools towards opening-up school learning for student entrepreneurship with community and industry (Zhao, 2012b). For stakeholders who were actively attempting to make changes in schools, greater strategic support could be provided by Tech Schools in terms of aligning the types support provided with the specific needs of stakeholders and coordinating actions between stakeholders. Table 9 presented how Tech Schools can transition from a stage 2 to a stage 3 impact by helping schools to align and coordinate stakeholder activities in project-based learning. Table 9 addressed the central research question through a synthesis of findings from the cross-case analysis. This was presented as a matrix consisting of Tech School mediation through intersections between alignment for depth and coordination for breadth of stakeholder involvement.

Finally, speculating beyond the scope of this study – Tech Schools as mediating organisations, could have a revolutionary impact on education by moving beyond industry and community input *in schools*, to moving aspects of schooling directly *into the community and industry*. For example, through an expansion of an ILC, student projects could be undertaken directly in industries or in community groups. This would represent a *distributed system of schooling* reminiscent of Illich's notion of "de-schooling" (1972/2002). The role of a Tech School could be to manage the ILC (s) as a network of smaller mediating organisations coordinating between industries and schools to meet the specific requirements of education. Schools would have a crucial role in connecting projects to curriculum and integrating assessment into projects. This has been titled a "stage 4" impact of Tech Schools as mediating organisations. Figure 10 is a summary of the four stages of Tech Schools as mediating organisations for integrating STEAM in schools. Colour coding matches Analytical Framework 2. Part 1 of the conclusion will conclude by answering the central research question through a summary of the answers to the four sub-questions.

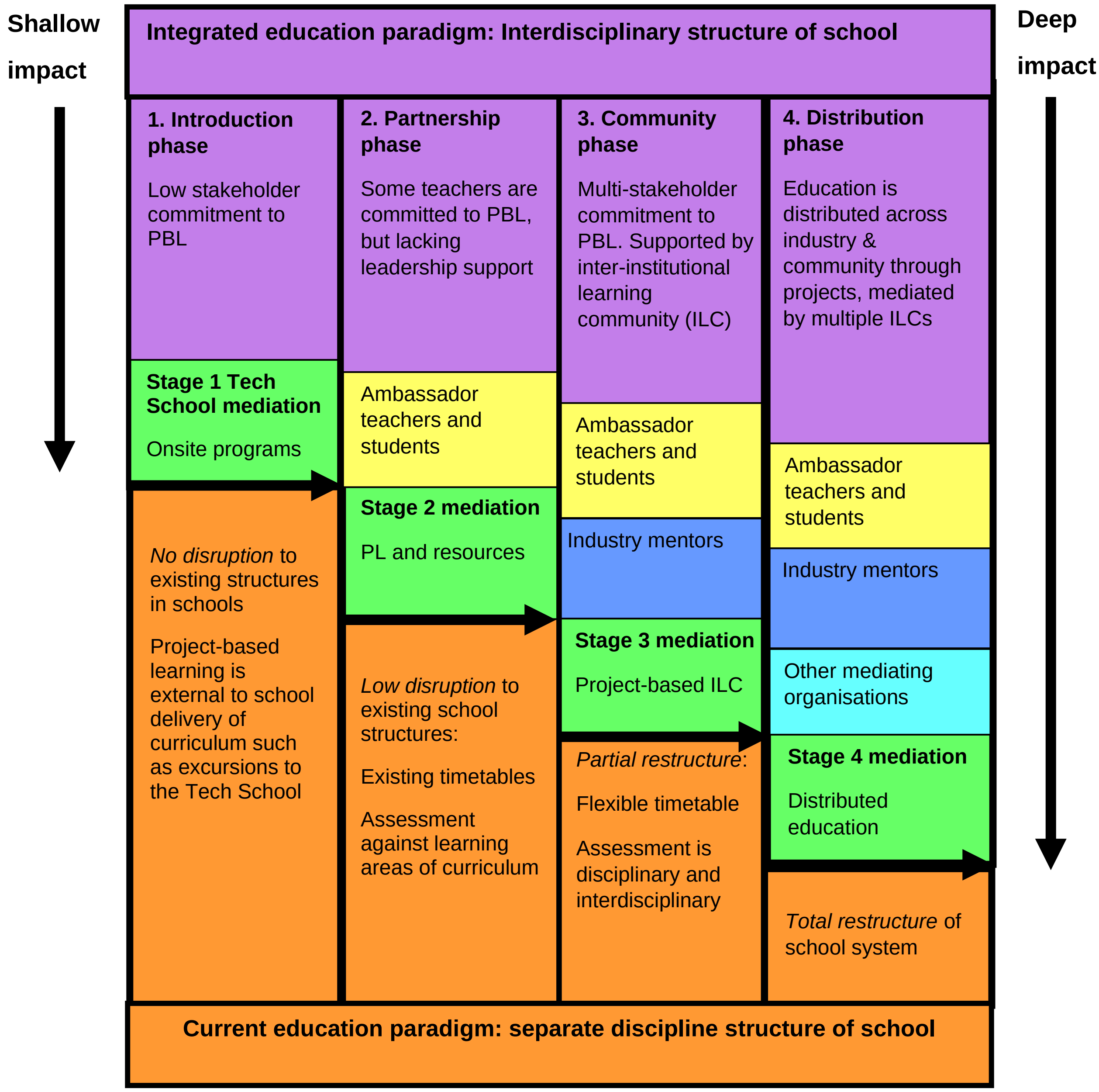


Figure 10. Stages of Tech Schools as mediating organisations for STEAM integration.

Answering the Research Question at a Local Level with Reference to Case Study Analysis

How can Tech Schools as mediating organisations promote student, teacher and school engagement in authentic STEAM projects?

Answer to the research question: Stages of Tech School impact.

Tech Schools as mediating organisations for promoting stakeholder engagement in STEAM projects are multilayered, with the initiative being enacted in stages of increasing impact on the system of education.

Stage 1 of Tech Schools as mediating organisations, has been focussed primarily on *introducing stakeholders to project-based programs*. These programs promote student agency and authentic learning outcomes. Professional development workshops for teachers have been centred on the design thinking process and constructivist pedagogies using new technologies. Support for teachers in planning, implementing and evaluating projects in secondary schools has been limited by the constraint of teaching the curriculum through separate subjects structured in short periods of time.

Stage 2 of Tech Schools as mediating organisations, is focussed on *working within existing school structures to integrate authentic projects in schools*. The codesign of programs and competitions with industry provide schools with opportunities to connect school learning with real industry and community issues. The development of educational resources such as curriculum aligned rubrics, online tutorials, frameworks and unit plans are an example of practical tools for integration.

Stage 3 of Tech Schools as mediating contexts is predicted to involve an *expansion and formalisation of the network of stakeholders* by supporting: the alignment of the personal motives; the relational capabilities and the collective skills of students, teachers, interdisciplinary school leaders and industry/community leaders. It would require coordinating the activism of individual stakeholders in professional learning activities to develop collective action, through an interinstitutional learning community (ILC), focussed on shifting structural constraints to fully integrate authentic project-based learning in schools.

As Tech Schools evolve through each stage of their development as mediating organisations with increasing depth and breadth of impact on education, how they support teachers and other stakeholders also evolves. Already a shift from, Tech Schools being distinct from mainstream education, to engaging with teachers and leadership within schools is noticeable. An example of this is, the move from schools visiting the facility and having programs delivered to teachers and students (stage 1), to Tech Schools helping specific schools embed project-based learning within a traditional timetable and subject-based assessment (stage 2). The development of informal groups of student and teacher ambassadors, Tech School educators and a group of local industries interested in engaging in school-based projects reflects a transition into stage 3 Tech School mediation. For Tech Schools to have a long-lasting and meaningful impact on shaping education through authentic engagement with industry and community projects, the initiative will need to develop further within a stage 3 impact.

This will require increased collaboration and commitment from all stakeholders towards changing educational structures. It will also require Tech Schools to engage more overtly in the political context of education as positive disruptors to the system. This represents a *stage 4* development for Tech Schools as part of a distributed learning model with ILCs mediating student projects out of school, in the community and learning departments of industries.

Part 2: The Political Context

Reviewing the Research Question: Recommended Actions for Tech Schools

Expanding beyond the local context of Tech School mediation with secondary schools requires broadening the lens of analysis from the specific cases studied to the *broader themes of education*. Part 1 of the conclusion outlined how existing school structures were an obstacle to integrating STEAM projects in schools and how Tech Schools could mediate the structural changes needed to schools in stages. Part 2 makes the same argument for Tech Schools as mediating the structural changes to education more broadly to align education with social and industrial developments of the 4IR. Further, Tech Schools as a political initiative should report research conducted at a local level with schools to make recommendations on systematically reshaping education to better prepare students. In this way, Tech Schools could act as mediating organisations between educational research and educational politics. This is represented in the conceptual framework for the study. Refer to Chapter 3 for an explanation of key features of the conceptual framework.

The conceptual framework has been used for structuring the literature review, designing the methodology of the study, selecting the case studies and developing the analytical frameworks. The conceptual framework will now be used to make recommendations based on the analysis of data and its relationship to the literature. These recommendations are intended as a guide for *utilising Tech School engagement with schools as a means for achieving political reforms to education*. This represents the dialectical relationship between Tech Schools as local and political mediating contexts.

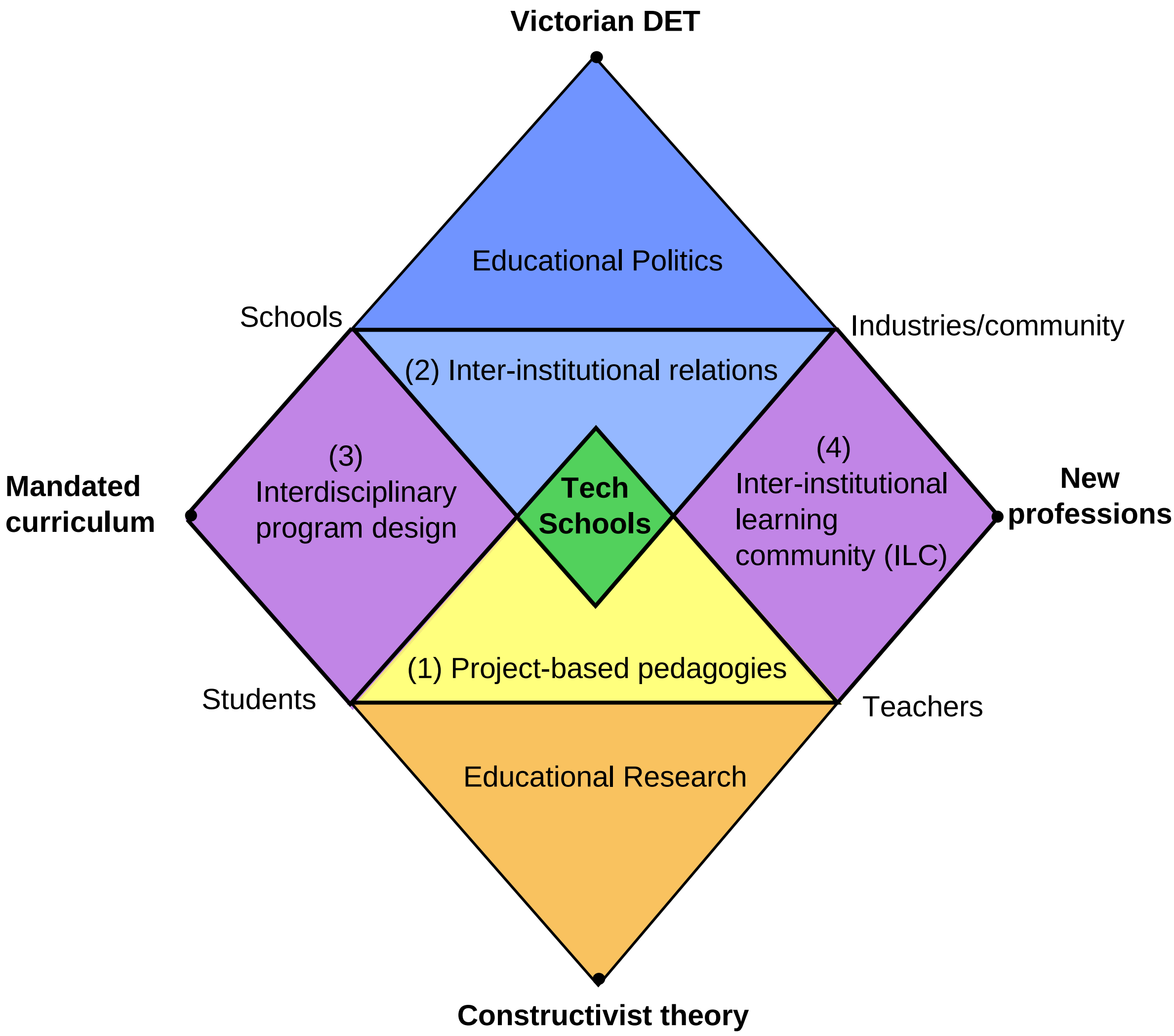


Figure 11. The central role of Tech Schools in mediating an education reform.

Tech Schools as mediating organisations (green diamond) are an opportunity for reconstructing the existing framework of education through an integration of educational research (dark yellow) and educational politics (dark blue). Figure 11 incorporates the key features of Tech Schools as mediating contexts by relating Analytical Framework 1 focussed on project-based pedagogies (pale yellow) with Analytical Framework 2 focussed on inter-institutional relations (pale blue). The use of these frameworks for analysing case studies of Tech School mediation at a local level, revealed that two key activities were needed to support the integration of authentic projects in schools: Interdisciplinary program design and ILCs. These are shown in purple.

(i) Interdisciplinary program design.

Tech Schools could help secondary schools to reorganise the delivery of the Victorian and the Australian Curriculum through the design of interdisciplinary school programs which connect with local industry and community, and allow students to learn the essential content from each learning area. *Interdisciplinary frameworks* and *curriculum-aligned rubrics* are some of the practical resources which Tech Schools can provide to support structural reforms in schools. Analysis of case study findings suggests that well-designed interdisciplinary projects could deliver curriculum outcomes as effectively and more authentically than teaching curriculum through separate subjects. This claim requires further research to be substantiated. The use of the *design thinking process*, and structured *design challenges* and *projects with industry and community* were examples of new approaches to school programming for project-based learning which add to an international body of case study research by A. Diefenthaler et al. (2017); Fullan et al. (2018). It also provides a specific approach to STEM and STEAM education, building off literature by Harris and De Bruin (2017) and Thomas and Huffman (2020b) presented in Section 2 of the literature review.

(ii) Inter-institutional learning communities (ILCs).

Tech Schools could help schools to coordinate and align the actions of key stakeholders through ILCs with formalised roles spanning the school and work context such as industry/community mentors, interdisciplinary leaders and teacher/student ambassadors. Opening-up schools to allow authentic industry and community input requires reforms to the education profession and potentially industry through *new professional roles* (Lucas et al., 2013; Zhao, 2012b). Further, the notion of professional learning communities (PLCs) in schools is not sufficient as authentic projects are not taught *in schools* but *across the community and industry*. For this reason, aspects of project-based learning could be undertaken directly in industries and community organisations with qualified mentors who work across contexts. In this way ILCs represent a structured approach to a *distributed education model*.

In summary, Tech Schools could help schools to reform towards a project-based learning structure through two mechanisms: designing interdisciplinary programs that deliver the mandated curriculum and ILCs that create new professions in education. Yet, neither of these activities can occur without broader level support in the form of (a) research and (b) political action. Tech Schools can *mediate between* *the local and broader contexts of education* through engagement in research and political action to achieve school reforms. This will require Tech Schools to *formalise* their engagement with schools through both types of activities.

(a) Research activity.

Formal *research is needed to collect evidence of interdisciplinary project design* in schools which authentically engage with industry/community and deliver achievement standards for the learning areas of the curriculum. Tech Schools are an ideal context for conducting publishable research on project-based reforms in schools. This research could serve as a scaffold for reorientating the curriculum towards authentic project-based learning. It is recommended that the Tech School initiative develop a *research department* for this purpose in collaboration with universities, government, industries and other educational mediating organisations.

This thesis is intended to serve as a map of the different facets of Tech School mediation which can serve as future research focus areas. Possible research areas outlined in the literature review include: constructivist/constructionist pedagogies using new technologies (L. Harasim, 2012; Harel & Papert, 1991); the design thinking process for school programming (A Diefenthaler et al., 2017; Luka, 2014); innovative learning environments (Alterator & Deed, 2018; Kenn Fisher, 2016); school-industry partnerships for authentic practices (Australian Industry Group, 2017; Education Services Australia, 2018); and subject integration and curriculum assessment through interdisciplinary STEAM projects (Bazler & Sickle, 2017; C. Quigley et al., 2017; Thomas & Huffman, 2020b).

(b) Political activity.

Tech Schools as mediating organisations for managing ILCs could provide a *platform for political discussion and action* related to the creation of new professions that span education, society and industry. The current lack of relationship between education, society and industry was explained in Section 1: Part 1 of the literature review. A broader appraisal of how professions are evolving in the 4IR is needed to create a more balanced vision of industrial progress that is not dominated by overspecialisation in STEM (Section 1: Part 2 of the literature review). The need to better prepare students for the impact of technology on the workplace has been a central theme of the thesis, yet this *does not entail privileging one subject area over another* – such as science and mathematics over the humanities and the arts in education (Karp, 2020, 19 June ; Stokes, 2018). Nor should technological advancement emphasise one set of capabilities over another in the workplace – such as data analysis and coding over building social networks or sustainability (Lucas & Smith, 2018; Taylor, 2016). For these reasons, this thesis argues that STEAM is not a straight forward expansion of the current STEM narrative, but a provocation to critically evaluate how shifts in Australian education expand or reduce opportunities for all students to shape an innovative, ethical and democratic society.

Finally, having local level ILCs with education, industry and community leaders collaborating on projects promotes a notion of progress which is mutually beneficial. This ensures that progress in the 4IR means progress for *all* members of society (Schwab, 2018). Just as industry has a key role to play in *reforming education* towards engaging, authentic and relevant learning for students, education should have a key role in *reforming industry* to value life-long learning as its primary asset for growth (Field & Leicester, 2001).

A summary table of the relationship between Tech Schools' mediation at the local school-reform level and the broader education-reform level is presented.

Table 10
Tech Schools: Dual-Level Mediating Organisations for Education Reforms

Tech School Activity	Local school level	General education level
Program design	Interdisciplinary units	Reorganising the curriculum
Establishing local ILCs	New roles for teachers & students	Political platform for collaboration between stakeholders in education
Research: Constructivist pedagogies	Formal research relationship with schools acting as case studies	Evidence for project-based reforms to schooling
Politics: Interdisciplinary STEAM	Policies for structural change to timetabling and subject silos	Diversified engagement between education, community/industry leaders

Further Research with Tech Schools Beyond this Study

The research study has highlighted areas of action which can be initiated at a local level in secondary schools to support STEAM project integration as well as fertile areas of further research for broader changes to education. During the course of this study, some concrete resources for project integration in schools were developed to support secondary school teachers who expressed a desire to embed Tech School projects in their schools. This included the design of:

- A unit plan with connections to curriculum, industry engagement and support from their Tech School (Appendix E)
- Generic STEAM rubrics for Tech School projects aligned to the Victorian Curriculum (Appendix F).
- An online resource booklet compiled by all Tech Schools to support teachers in professional learning workshops.

Tech Schools as research hubs.

These resources developed as part of the research study on Tech Schools demonstrate how collaboration between teachers and Tech Schools for STEAM project integration can be *supported by university research*, which fosters critical discussion and action centred on positive disruption. As research hubs, Tech Schools provide an ideal context for collecting data on innovations in education, while university research provides an ideal platform for Tech Schools to communicate their innovations to a wider public and academic audience. For this reason, ongoing collaboration between university researchers and Tech Schools is recommended, with Tech Schools acting as *research institutions for educational innovations*. It is predicted that this would require an expansion of Tech Schools and their further integration into the higher education system, potentially as a research course for undergraduate, PhD and post-doctoral research students. This could also include placements for pre-service teachers with an interest in STEAM project-based pedagogy and program design.

Final recommendations and new questions.

Beyond supporting local schools, Tech Schools as mediating organisations can support broader disruption of the education system through policy change as Tech Schools are a political initiative. Yet, this also creates a tension as Tech School impacts are currently measured using key performance indicators (KPIs) which relate to promoting student participation in STEM subjects, not the integration of projects in schools. This was a noted limitation of the Tech School initiative in the case studies presented, which makes a case for a review of Tech School goals. Based on the findings from this study, the following changes to Tech School goals are recommended:

- The Victorian DET should change its Tech School branding from STEM to STEAM to encourage greater interdisciplinarity in schools.

- Tech Schools should engage with school leadership to enable projects to be embedded in school structures. This would require KPIs to be focussed more on involvement with teachers in schools, rather than the number of students attending onsite programs through excursions.
- Tech Schools should collect research on secondary schools which are changing existing school structures such as timetabling, subject integration and industry engagement to support STEAM projects in schools. These schools can serve as champions for positive disruption to the education system.

These recommendations represent a transition of Tech Schools from stage 1 and 2 impacts to stage 3 and 4 impacts which may inform Tech Schools' longer-term planning. It can be argued that without this proactive role of Tech Schools as *mediators for school level change*, schools may invest time and energy in initiatives with greater tangible benefits for teachers and leadership. This raises some fertile questions for future research on Tech Schools such as:

- How willing is the Victorian DET to disrupt existing school structures and what role would Tech Schools play in this disruption?
- Do Tech Schools represent a necessary break from artificial means and measures of schooling such as high stakes exams, curriculum-centred teaching, subject silos and ATARs, towards authentic community and industry engagement?
- Is constructivism once again a valuable theoretical construct to be applied to school learning through STEAM projects?

These questions serve as provocations for disrupting an outdated system of education, rather than neutral questions for researching Tech Schools. Yet, they are a reminder that Tech Schools are not solely designed to promote STEM, nor to facilitate project-based learning within existing school structures. This would overlook the disruptive potential of Tech Schools for reshaping the education system to have greater relevance to work and life in the 4IR.

Thesis conclusion

This thesis was undertaken to understand the educational purpose of Tech Schools and the political context from which they have emerged. Use of a comparative case study methodology provided examples of the value of Tech Schools from the perspective of different stakeholders, with a particular emphasis on school teachers. The use of analytical and conceptual frameworks enabled cross-case analysis for key themes to be synthesised and related to the broad political context of the Tech School initiative. This partially overcomes the limitation of generalisation from researching only two of the 10 Tech Schools. Further research across all sites is recommended to validate the general findings and recommendations from this study.

Overall, the study found that Tech Schools are partly a revival of previous endeavours in progressive education through constructivist pedagogies and project-based learning. Yet, they are also an innovation in developing alternative modes of delivering the curriculum and explicitly incorporating industry and community issues into school learning. A central insight from conducting this research was the conceptualisation of Tech Schools as “mediating organisations”. This concept served as a lens to analyse the diverse activities that Tech Schools undertake to relate schooling with industry and community groups through projects.

Case studies were selected to emphasise the distinct activities of Tech Schools as mediating organisations for supporting teachers to design, implement and evaluate projects in their own schools. Cross-case analysis revealed that school structures such as timetabling and subject silos need to be reformed to allow projects to be integrated into schools. Four stages of the strategic development of Tech Schools as mediating organisations were outlined with recommendations that Tech Schools increasingly focus their resources on two high impact activities. First, helping school leadership and teachers to reform school structures through *curriculum aligned interdisciplinary programs* rather than a timetable of separate subjects in set periods of time. Second, to formalise the relationship between schools, industry and community through the establishment of local *inter-institutional learning communities* (ILCs). This would allow input from industry and community in schools through mentors, and for schooling to be distributed into industries and the community through projects.

Designing projects through an ILC with formalised roles for all stakeholders would require *alignment* of stakeholder activities *within their institutions* and *coordination* between stakeholder activities *across institutions*. This represents an evolution of Tech School mediation: from the delivery of engaging programs, towards providing leadership and support for schools transitioning to integrated community-industry project-based learning.

The short-term recommendation for the Tech School initiative is to transition from a stage 2 impact: PD workshops and resources, to a stage 3 impact: the assimilation of projects into existing school structures. The long-term recommendation is for Tech Schools to transition from a stage 3 impact, to a stage 4 impact: supporting schools to develop interdisciplinary programs which directly engage with community and industry beyond the school. This redesign of education – including a review of the mandated curriculum and the profession of teaching – is needed because current school structures such as: the timetable, subject silos, hierarchical program management, curriculum driven teaching and standardised assessment of learning are impediments to integrating STEAM programs in schools and limit the impact of the Tech School initiative.

For Tech Schools to act as mediating organisations for school reforms will require: *formalising the process of research* to collect evidence of successful project-based programming in schools and *formalising the political platform* for discussions on future developments in education through ILCs. In this way, Tech Schools can become mediating organisations across three dimensions of educational impact: (1) for student projects, (2) for the project of reforming school structures and (3) for the project of integrating education, community and industry for societal progress.

In conclusion, this thesis examined how the socio-technological revolution restructuring industry created a political reason for Tech Schools. Tech Schools present education with a similar opportunity for a restructure to better prepare students for the 4IR. Schooling organised along a single developmental track (curriculum) made of disjointed parts (subjects) was suited to the past "one-dimensional society" of standardisation and competition (Marcuse, 1964, p. 1). The shift to interdisciplinary project-based STEAM programs could provide multiple learning pathways within an integrated educational landscape suited to a complex, interconnected society. For this reason, Tech Schools should *not only support schools to adapt, they should positively disrupt the current paradigm of school education*. This research study has provided a theoretical argument with evidence for this need to disrupt education in response to the 4IR and outlined the central role of Tech Schools as mediating organisations for this educational revolution.

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Appendix A1: Triangulation of data for the 3-Day Tourism program (program 1)

Personal Layer: Individual learning	
The program promoted student agency: -The class teacher stated: "you want to build the resilience to have the force to break through it, but you need to give them the resources for it." A positive comment was "the opportunity for them to experiment with some different apps that they might think they could use back at school for a more defined problem." - "They probably needed a little more time on the actual building and really muck around with the tech" - Student survey: 75% of students were satisfied with the program, although the rest were dissatisfied.	The educator personally connected with students: -Student survey responses: mostly students were not interested in the program, but were satisfied by the Tech School staff. 80% of students thought that they would not want to explore any of what they experienced at the Tech School. -The Tech School educator stated "We need a stronger 'why' introduced at the beginning". For students "to see why this is an exciting industry with some examples of other projects, to help them excite, ignite and engage" -The class teacher stated that: he was "impressed with the engagement of some of those kids. Particularly students who rarely produce work that they would be happy to present to others"
The program provided opportunities for personal growth of student capabilities: - Student survey: 90% of students stated that they learned something new -The class teacher stated that: The biggest challenge for the students was "coming up with the problem. Developing the problem, that's almost the creative thinking part in that they actually have to find their own issue. This was different to school, where students were usually told what to do and what problem to solve so coming up with their own problem to solve, is remarkably difficult for them." -The Tech School educator stated that: "a whole range of techniques such as the SCAMPER technique of modifying, replacing and substituting" could provide different directions for creating beyond ideating.	The teacher differentiated the program to meet students' specific needs: - The class teacher stated that: "some background information around the different tech" would help some visiting teachers to feel more comfortable supporting students at the Tech School. - Student survey: About half of the students found the level of difficulty just right, while the other half found it too hard. Only one student found it too easy. This suggests that there needs to be more scaffolding to help students who are struggling. One interviewed student commented that: "sometimes we didn't know what we were supposed to do because there was too much freedom. We didn't really get the help we needed, he was always pushing us along the path, to solve it yourself to learn" - The class teacher stated that: "The program itself, needs a bit of work. The app design one. Because for three days it felt like it was getting a bit stale. That is a long time to spend on just that one topic."
Lesson Layer: Relational learning	
The lesson encouraged students to interact as members of a learning community by fostering: The class teacher stated that using the design thinking terminology "is useful as a structure, to have a common vocabulary right across the school. Then we can build on it, and as teachers the more we become exposed to it, the better it will be for us and for the kids to hear that common vocab. It will be great for us."	The lesson reflected authentic work place practices such as: The class teacher stated that: an important part of the Tech School is "to show the kids the different areas they can end up by going through a STEM pathway. And that is where they are going to have an impact." - "It was great to see them have the time, even though it was sometimes too slow. To actually have the time to sit down and do a project over three days is amazing. Compared to here, we have 70 minutes."
A range of forms of assessment was used to evaluate student learning: The class teacher stated: "it needs to be very specifically curriculum-based for teachers, otherwise they think it is not getting anything done. It is a massive thing as there is pressure for it to be right as it is a document going out to parents." The teacher found that the program was not specifically relevant to his teaching but he did learn about STEAM. Student surveys: One interviewed student commented: "it was a good topic but it was made a lot more complicated that it could have been." The class teacher stated: "I liked the fact that they actually built something. Even though some groups did it to a higher level. They all actually ended up making something that was augmented reality and they actually achieved something"	Features of the learning environment utilised for active learning: -The class teacher stated that: "The facility is amazing! The kids will engage with it because it is different to what they have here. And it is full of all the different tech stuff that they love to use." -The Tech School educator stated that: the strength of the Tech School is "providing access to high functioning technologies" and an "alternate approach to learning including the physical space and the length of the program" (3 days). -Student survey: Satisfaction for the facility was high to very high. No students expressed dissatisfaction -The class teacher stated: "I think they need to try and get past that theory part and get them actually hands on doing something. And something big, a bit earlier."
Project Layer: Collective learning	
The students involved themselves in the project as team members: - The Tech School educator stated: "students are most challenged by the open nature of the program and expectations around collaboration". Allowing students to work with their friends in a group increased engagement although students tended to adopt "school-leadership styles of group work". - Student survey: 80% of students found working in teams easy. This is probably attributable to students being able to choose their groups and work with their friends.	The tools & resources enhanced learning outcomes: Student survey: Using new technology seemed to be what students enjoyed most The class teacher stated: "he (*the Tech School educator*) made a video of how to do something but then he never told the kids where it was. So, when the kids were stuck, they couldn't go back to it to help themselves. They were always waiting on him."
The project promoted diverse skills for team members: - The Tech School educator stated that: "problem-solving was an area that students struggled with, especially collaborative problem-solving". "The empathy and define stages of the design thinking process was also a challenge for students".	The design of the project related school learning to society: -The class teacher stated: Few students are aware of the wide range of jobs that are related to STEM "For students, when you say engineering, they only think of standing on a welder. They think it is the only job that goes with that profession." Student motivation in STEM could be improved by showing students "all different possibilities out there that they can go through." - Student survey responses: About two-thirds of the students said they would not like to do this sort of project back at school
Data collected: 20 students were surveyed using a modified Tech School survey. The class teacher was interviewed back at school after the program ended. The Tech School educator was interviewed straight after the end of the program. 4 students were interviewed as a group back at school.	

Appendix A2: Highlighted Standard Criteria for Evaluating a 3-Day Tourism Program

Personal Layer: Individual learning	
Program promotes ***student agency*** by encouraging students to: (1) develop new concepts and explore relationships between ideas (2) set & reflect on, and communicate personal goals (3) consolidate learning individually & with others (4) represent learning in varied ways such as stories, images, models (5) make choices in what and how they learn based on interest	Educator makes ***personal connections*** by drawing upon students': (1) interests, daily experiences, prior knowledge (2) peer groups, family, community groups, school (3) beliefs, thoughts, ideas, feelings, motivations, values (4) knowledge of professions and future plans (5) The educator's background was communicated to the students
Opportunities for ***personal growth*** of student capabilities through: (1) inquiring, questioning, measuring, testing and critiquing (2) developing and communicating new knowledge (3) collaborating with others (4) engaging in creative expression and construction (5) independently sourcing information and problem solving	Educator ***differentiates the program*** to meet students' specific needs by: (1) providing supporting resources & tools to scaffold learning (2) extending student thinking with questions, hypotheses & discussions (3) teaching strategies for problem solving (4) using open problems to encourage students to construct knowledge (5) giving individual feedback to students
Lesson Layer: Relational learning	
Students to interact as members of a ***learning community*** using: (1) diverse & creative ideas (2) student feedback on success & failure, and peer teaching (3) sharing, collaboration & voluntary participation (4) empathy & cooperation (5) roles, routines, procedures relevant to the learning context	The lesson reflects ***authentic work place practices*** such as: (1) meetings & conferences (2) formal & informal presentations (3) evaluations, critiques & feedback (4) Schedules, milestones & deadlines (5) negotiating rules & common values
A ***range of forms of assessment*** of student learning include: (1) using explicit learning objectives as criteria (2) self-reflections & peer assessment by students (3) formative/summative assessment by Tech School & class teachers (4) student development of capabilities (5) use of knowledge, skills & tools to solve real-world problems	Features of the ***learning environment*** utilised for active learning include: (1) varied learning spaces & furniture (2) ready availability of materials, low & high-technologies (3) tools for different purposes: new skills, curiosity, independent work (4) student-directed learning rather than lectures & demonstrations (5) authentic industry practices modified for student participation
Project Layer: Collective learning	
Students involve themselves in the project as ***team members*** by: (1) emotionally & intellectually identifying with a common problem (2) Sharing knowledge & ownership of project amongst all members (3) fairly dividing the labour amongst members (4) valuing the input of all members and utilising their expertise (5) coordinating individual actions to achieve the goal	***Tools & resources*** enhance learning outcomes by enabling teams to: (1) produce quality prototypes & convincing solutions to problems (2) learn new skills & knowledge transferrable to other tasks (3) support independent problem solving and ownership of learning (4) externally represent & communicate their knowledge (5) Rethink & improve prior knowledge through designing, building & testing
The project promotes ***diverse skills*** by encouraging teams to: (1) investigate, research, interpret & experiment (2) question assumptions, critique ideas and consider alternatives (3) utilise the affordances of materials, technologies & theory (4) use a variety of means to design solutions to problems (5) reflect on what the group learned and how to improve	The design of the project ***relates school learning to society*** by: (1) requiring authentic solutions to actual community/industry issues (2) allowing students to share their knowledge with the community (3) embedding the school curriculum into practical experiences (4) drawing on the latest technology and knowledge used 'in the field' (5) suggesting ways that the project can further learning in/out of school

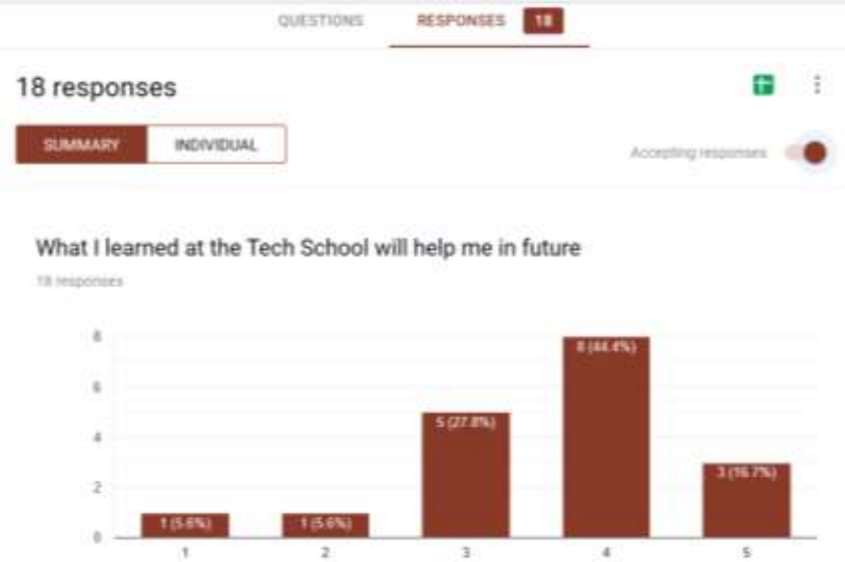
Appendix B1: Triangulation of the 3-Day poverty inquiry program (program 2)

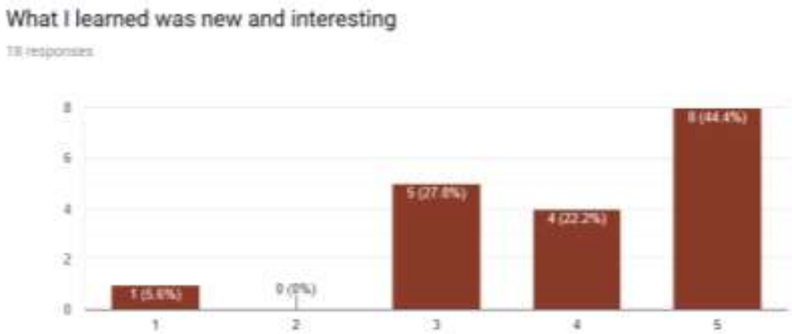
<table>
<tr><th colspan="2">Personal Layer: Individual learning</th></tr>
<tr><td>The program promoted student agency:
Survey: I was able to share ideas about what I wanted to achieve in class (72.2%)
Tech School educator 2: 'we often let them be more self-guided in their learning and when we plan things. Which can be quite overwhelming for everyone at the start'
Tech School educator 2: 'they can't believe that we are trusting them with the technology and equipment, which is quite amazing for us to hear in that we want to provide them with those opportunities'
Tech School educator 1: 'It is also about giving them space to go off and develop their own skills.'</td><td>The educator personally connected with students:
Survey: What I learned at the Tech School will help me in future (61.1%)
How satisfied were you with how the Tech School teachers and staff treated you? (83.3%)
Tech School educator 1: 'Here it is about learning something new and getting those skills intact and applying those skills in something that they might be interested in.'
Tech School educator 1: 'conversations that I sometimes strike are to get them to think beyond the classroom and then to link their goals to what they are seeing in the classroom.'</td></tr>
<tr><td>The program provided opportunities for personal growth of student capabilities:
Survey: Overall, how satisfied are you with your Tech School experience? (94.4%)
Survey: What I learned was new and interesting (66.6%)
Tech School educator 1: 'to move beyond the content and to focus on what it is that you are doing, what are the skill sets that you are practising here.'</td><td>The teacher differentiated the program to meet students' specific needs:
Survey: I was able to do what the Tech School teacher asked with help (88.9%)
Tech School educator 1: 'sometimes for those challenging kids the teacher can just give up. One of the students actually said to their teacher 'So, you don't really believe that we can do it, can you?' It is often like a domino effect. Once they start getting that train of thought, they don't have confidence in themselves and completely shut off. They don't think about the future and they don't believe in themselves.'</td></tr>
<tr><th colspan="2">Lesson Layer: Relational learning</th></tr>
<tr><td>The lesson encouraged students to interact as members of a learning community by fostering:
Tech School educator 2: 'leadership have tried to hire people from very diverse backgrounds so that we can draw on people's expertise. So that has been really helpful to help each other out in those respects.'</td><td>The lesson reflected authentic work place practices such as:
T: So, if it clearly explained that this is the pre-work that you do, which is the theory. And getting familiar with idea of Empathy, Ideation and figuring out a solution. How you can raise awareness of homelessness and poverty in your community'
Tech School educator 2: 'I think it is quite a mature environment, in the way that we approach the programs. That students are working on a project and can be quite self-directed in their learning'
Tech School educator 2: ' I think that looking at problems not at discrete subjects but from a multidisciplinary angle, the way that we work in life'</td></tr>
<tr><td>A range of forms of assessment was used to evaluate student learning:
Teacher: 'You can incorporate this across the board. You can tie it to the curriculum and make the assessment something like this, where they are actually doing hands-on stuff. It can culminate in this being there assessment rather than a test. And for the kids the engagement is there.'</td><td>Features of the learning environment utilised for active learning:
Survey: How satisfied were you with the Tech School learning spaces and technologies? (83.3%)
Survey: What was the best part of learning at the Tech School?
Most responses were related to using equipment and technologies. Specifically, 3D printing and programming were highlighted as the best part of learning.</td></tr>
<tr><th colspan="2">Project Layer: Collective learning</th></tr>
<tr><td>The students involved themselves in the project as team members:
Our group worked well together (94.5%)
-Tech School educator 2: 'I think also working in teams can be quite confronting for students who are not doing it as much in their classrooms as we do here, when you are working on project together and trying to come out with an outcome in a short space of time. And I think having to manage time as well'</td><td>The tools & resources enhanced learning outcomes:
Teacher: 'Getting them out of the classroom and doing hands on stuff like this while tackling the theory side of it first, I think this is a really good way to deliver any sort of curriculum to the kids.'
Teacher: 'The lead up was a bit touch and go because we weren't really familiar with what we were going to do here'
Tech School educator 1: 'they(teachers) come here and get a taste, they see the pedagogy in play and how the kids are involved in the programs, the computer programs, the materials, the laser cutting and they now know that all of these capabilities (resources) are now here'</td></tr>
<tr><td>The project promoted diverse skills for team members:
Tech School educator 2: 'I think that experience of the skill development that we are trying to focus on can be quite confronting for some students. The technology, the digital literacy skills we are trying to develop and when you are exposed to a lot of new technology in a short space of time'</td><td>The design of the project related school learning to society:
Survey: Our group developed a solution which would help an industry or community (77.8%)
Tech School educator 2: 'we are getting away from that subject learning, which is more multi-disciplinary.'
Tech School educator 1: 'this is just a taste for teachers for how they can utilise this type of thinking and teaching pedagogy into their own particular subject. It gives them some ideas of how they could run their Humanities class or their Science class in a different way'</td></tr>
<tr><td colspan="2">Data collected:
18 students were surveyed using a modified Tech School survey. The class teacher was interviewed at the Tech School. Two Tech School educators were interviewed on the last day of the program. No students were interviewed.</td></tr>
</table>

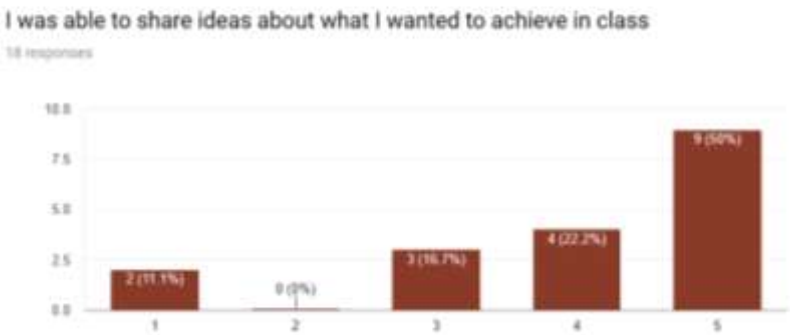
Appendix B2: Highlighted Standard Criteria for Evaluating the 3-Day Poverty Inquiry Program

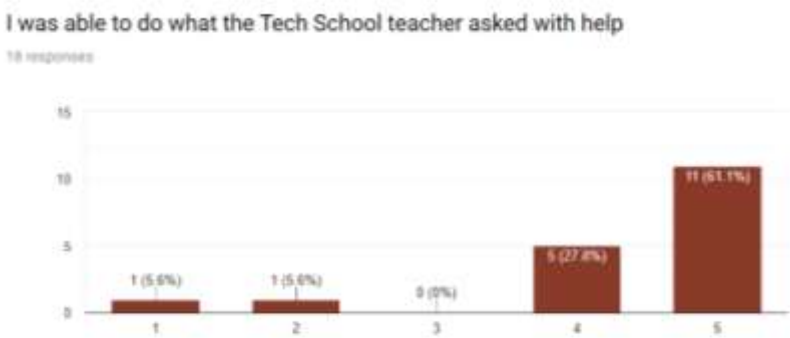
Personal Layer: Individual learning	
Program promotes ***student agency*** by encouraging students to: (1) develop new concepts, explore and connect their ideas (2) set & reflect on, and communicate personal goals (3) consolidate learning individually & with others (4) represent learning in varied ways such as stories, images, models (5) make choices in what and how they learn based on interest	Educator makes ***personal connections*** by drawing upon students': (1) interests, daily experiences, prior knowledge (2) peer groups, family, community groups, school (3) beliefs, thoughts, ideas, feelings, motivations, values (4) knowledge of professions and future plans (5) The educator's background was communicated to the students
Opportunities for ***personal growth*** of student capabilities through: (1) inquiring, questioning, measuring, testing and critiquing (2) developing and communicating new knowledge (3) collaborating with others (4) engaging in creative expression and construction (5) independently sourcing information and problem solving	Educator ***differentiates the program*** to meet specific student needs by: (1) providing supporting resources & tools to scaffold learning (2) extending student thinking with questions, hypotheses & discussions (3) teaching strategies for problem solving (4) using open problems to encourage students to construct knowledge (5) giving individual feedback to students
Lesson Layer: Relational learning	
Students interact as members of a ***learning community*** through: (1) diverse & creative ideas (2) student feedback on success & failure, and peer teaching (3) sharing, collaboration & voluntary participation (4) empathy & cooperation (5) roles, routines & procedures relevant to the learning context	The lesson reflects ***authentic work place practices*** such as: (1) meetings & conferences (2) formal & informal presentations (3) evaluations, critiques & feedback (4) schedules, milestones & deadlines (5) negotiating rules & common values
A ***range of forms of assessment*** for student learning include: (1) using explicit learning objectives as criteria (2) self-reflections & peer assessment by students (3) assessment by Tech School & class teachers (4) student development of capabilities (5) use of knowledge, skills & tools to solve real-world problems	Features of the ***learning environment*** used for active learning included: (1) varied learning spaces & furniture (2) ready availability of materials, low & high-technologies (3) tools for different purposes: new skills, curiosity, independent work (4) student-directed learning rather than lectures & demonstrations (5) authentic industry practices modified for student participation
Project Layer: Collective learning	
Students involve themselves in the project as ***team members*** by: (1) emotionally & intellectually identifying with a common problem (2) sharing knowledge & ownership of project amongst all members (3) fairly dividing the labour amongst members (4) valuing the input of all members and utilising their expertise (5) coordinating individual actions to achieve the goal	***Tools & resources enhance learning*** outcomes by enabling teams to: (1) produce quality prototypes & convincing solutions to problems (2) learn new skills & knowledge transferrable to other tasks (3) support independent problem solving and ownership of learning (4) externally represent & communicate their knowledge (5) rethink & improve prior knowledge through designing, building & testing
The project ***promotes diverse skills*** by encouraging teams to: (1) investigate, research, interpret & experiment (2) question assumptions, critique ideas and consider alternatives (3) utilise the affordances of materials, technologies & theory (4) use a variety of means to design solutions to problems (5) reflect on what the group learned and how to improve	The design of the project ***relates school learning to society*** by: (1) requiring authentic solutions to actual community/industry issues (2) allowing students to share their knowledge with the community (3) embedding the school curriculum into practical experiences (4) drawing on the latest technology and knowledge used 'in the field' (5) suggesting ways that the project can further learning in & out of school

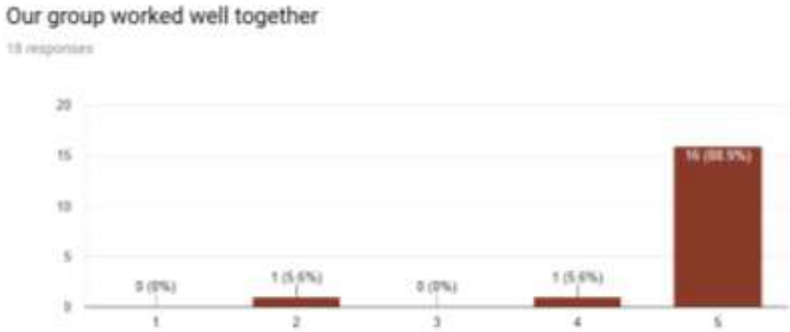
Appendix C: Screen shots of student survey data from 3-day poverty inquiry program

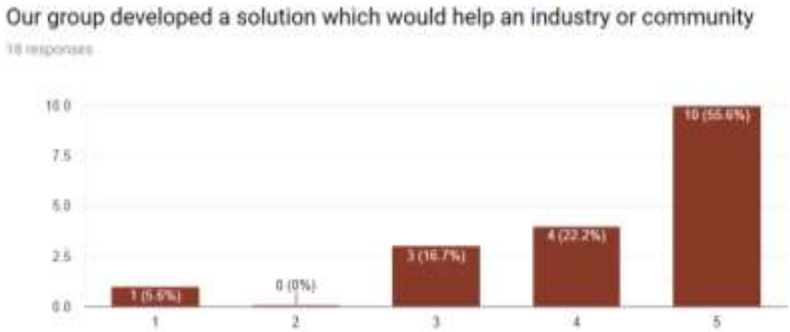


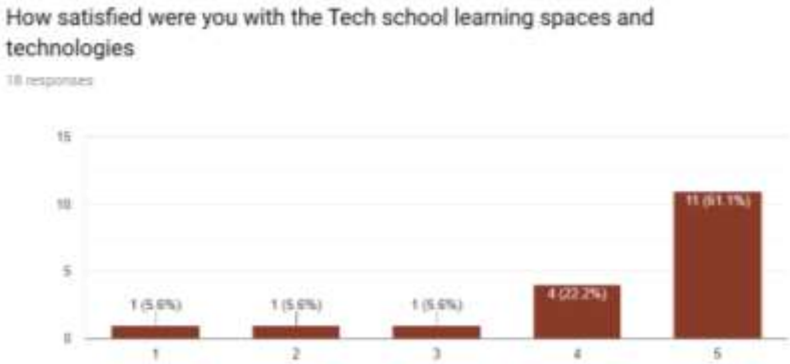


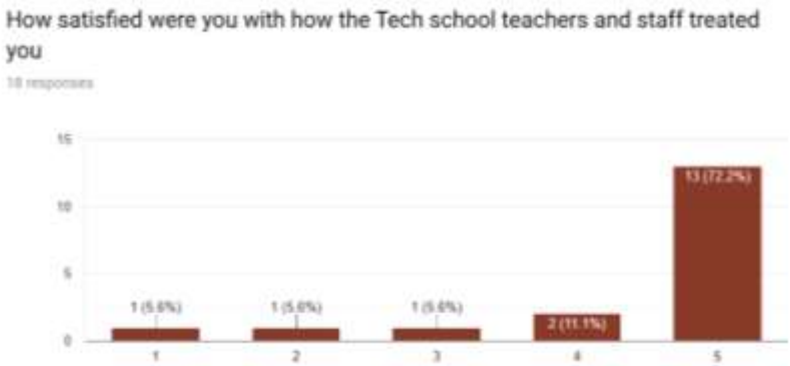





Our group worked well together
18 responses
0 (0%)
1 (5.6%)
0 (0%)
1 (5.6%)
16 (88.9%)

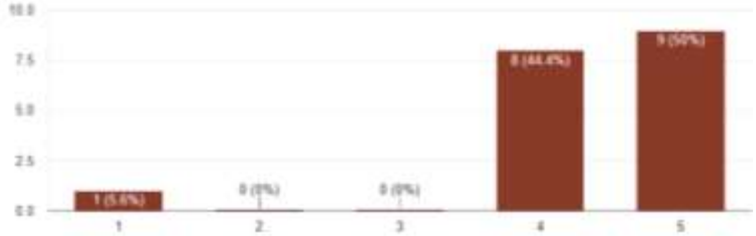

Our group developed a solution which would help an industry or community
18 responses
1 (5.6%)
0 (0%)
3 (16.7%)
4 (22.2%)
10 (55.6%)


How satisfied were you with the Tech school learning spaces and technologies
18 responses
1 (5.6%)
1 (5.6%)
1 (5.6%)
4 (22.2%)
11 (61.1%)


How satisfied were you with how the Tech school teachers and staff treated you
18 responses
1 (5.6%)
1 (5.6%)
1 (5.6%)
2 (11.1%)
13 (72.2%)

Overall, how satisfied are you with you tech school experience? 1 = not at all; 5 = extremely satisfied.

18 responses



What was the best part of learning at the Tech School?

18 responses

- working with the equipments that ive never used or seen before
- the new technologies
- getting to use technology and do hands on activigtititieds
- nothing
- the computer program
- the computer quality/shane
- Creating 3D objects we designed
- the equipment
- the 3d printing
- 3D printing and programing
- being able to learn to use different programs and being abl to be creative
- shane

- Creating 3D objects we designed
- the equipment
- the 3d printing
- 3D printing and programing
- being able to learn to use different programs and being abl to be creative

Some responses missing (included in Excel spreadsheet)

What is something that could be improved at the Tech School?

18 responses

- nothing
- nothing, everything it perfect
- no comment
- programs that are specific on people's intertests
- accesible food
- nothing really
- freedom
- idk
- n/a
- food accessability
- The school

Thank you for coming to the Tech School. We look forward to seeing next time. If you would like to leave any other comments, please include them below.

7 responses

- nothing
- Thank you for this experience
- :)
- thanks for having us
- You da best
- was very entertaining and something new that we got to experience using the advances technology Thank you for having us
- it was fun

Appendix D1: Method of preliminary data analysis for case study 1.

The complete data collection and analysis process for evaluating the Tech School programs involved:

Data collection.

1. Detailed observations of the entire Tech School program (3 days).
2. Survey of students at the end of the program (using the researcher's own survey).
3. Interview with one of the school teachers participating.
4. Interview with one or more of the Tech School educators who delivered the program, the program designer and the Tech School director.
5. Interview with a group of students who participated in the program (Tech School A).

Primary analysis.

1. Observation records were organised into categories which aligned with the analytical framework and standard evaluation criteria. These provided qualitative examples of different student and educator actions taken during the program as evidence of pedagogical practice. provides an excerpt as an example.

2. The standard evaluation criteria was used to analyse the observation records and evaluate using a heat map. Highlighted criteria were used for direct comparison between multiple Tech School programs.

3. Student survey data and interview data were triangulated using the evaluation framework. Areas of strength and potential issues identified from the standard criteria were related to interview comments and surveys to provide context for the evaluation.

Secondary analysis.

Cross-case analysis was conducted using Analytical Framework 1 to examine differences and similarities between programs, predict possible causes and generalise findings

Program 1: Tourism: An AR Showcase.

An example is provided of an observation record for one of the 12 criteria (Criterion 4-Differentiation). Chapter 4 (page 156) has an example of the 12-criteria template used to organise and analyse the observations.

Observation record for one criterion (Criterion 4: Differentiation)

4-The teacher ***differentiated the program*** to meet students' specific needs by: (1) providing supporting resources & tools to scaffold learning (2) extending student thinking with questions, hypotheses & discussions (3) teaching strategies for problem solving (4) using open problems to encourage students to construct knowledge (5) giving individual feedback to students
Please provide examples of these successful learning moments, and improvements to be made. Examples of success: (2) The educator probes students' problem-solving strategies with questions about what they have tried, and what they could try in future to independently solve problems. (4) The tourism program is open in terms of how students will use AR to help the industry. (5) The educator listens carefully to what students in each group have to say about their project. He helps them to resolve the problems themselves by using prompting questions rather than giving solutions. For example, "Can you redefine the problem? What do you need? Can you make a list of what needs to be done?'" Recommended improvements: (1, 3) While the educator encourages students to independently problem solve, some students experience frustration at not being able to solve technical issues. If there were supporting resources such as trouble shooting guides, then the students wouldn't be so dependent on the educator and feel personal frustration with him for not helping them. The program could provide tools and resources to overcome the students' sense of helplessness when faced with a technological challenge.

This process was repeated for all 12 criteria of success. Criteria highlighted in the observation analysis were transferred to the standard criteria table without comments. Refer to the heat map code below for interpreting the highlighted criteria.

Heat map code.

Overall level of success in each criterion of constructivist pedagogies based on number of examples from the list

Heat Map Code for Standard Evaluation

0 examples	No examples observed	
1 example	Minimal examples	
2 examples	Moderate number of examples	
3 examples	High number of examples	
4 examples	Very high number of examples	
5 examples	Very high number of examples	
Highlighted examples		
Highlighted recommendations		

Appendix D2: Synthesis of key aspects from evaluation of two Tech School programs

Criteria	Program 1: Tourism showcase	Program 2: Poverty inquiry	Key ideas for success from synthesis
Personal Layer: Individual learning			
Student agency	-Experiment with technologies -30 sec elevator pitches -Choice in how to work -Need support for independent work	-Opportunities for self-guided learning -Students comfortable sharing ideas -Need to encourage students to share their goals and daily plans	-Allow time for experimentation and self-guided learning with scaffolding. Promote choice in how to work and sharing of ideas, goals and plans.
Growth of capabilities	-Promoted new ways of thinking about the issue, new skills and knowledge -Need more creative thinking strategies	-Very high student satisfaction in Tech School but program could be more interesting with new learning -Need to include measuring, testing and communicating knowledge	-For student interest, encourage new ways of thinking about the topic, developing new skills, strategies and knowledge including creative thinking, testing and communicating.
Personal connection	-Need to relate to student interest and experience -Need to define purpose of program -Involve school teacher more for student engagement	-Need more connection to future plans and pathways for students -Excellent development of prior knowledge through a program booklet used in school before attending	-Define the purpose of the program by making explicit connections to students' experiences, interests and their future plans. Connect program to school with pre-work and involve the school teacher.
Program differentiation	-Could have a range of challenge levels and vary the pace more -Need problem solving strategies -Trouble-shooting guides needed for design and technology issues -Prep resources for teachers needed	-Excellent support for students with different levels of experience -Workshop on Tinkercad software -Visual organisers and strategies to help students empathise, define and ideate. Could support prototyping more	-Provide simple trouble-shooting guides for independently problem-solving technology, short workshops and preparation resources for teachers. Use visual organisers and strategies for stages of the design thinking process.

Criteria	Program 1: Tourism showcase	Program 2: Poverty inquiry	Key ideas for success from synthesis
Lesson Layer: Relational learning			
Learning community	-Design thinking terminology used -Different students testing AR apps -Promote more voluntary participation from students	-Design thinking process helped scaffold sharing and collaboration -Some team teaching based on educator expertise was good	-Use the design thinking process and terminology to scaffold project learning. Promote voluntary participation from students and product testing with other students, as well as team teaching.
Assessment of learning	-Pitch as real-world assessment was authentic -More connection to curriculum needed -Embed project into a unit of work	-Not enough time for student reflection and no assessment -Could use the booklet in the program -Needed to test prototypes -School teacher keen to embed program in a school unit	-Have a mix of informal assessment such as testing prototypes, pitching and student reflections and formal assessment connected to curriculum and embedded in a school unit.
Authentic practice	-Used project milestones, conferences and presentations -Needed to make a stronger link to STEAM pathways and professions	-Used milestones and deadlines -Pre-work at school meant students had a good understanding of the topic -Interdisciplinary focus in program	-Connect the project to school with pre-work and connect to STEAM pathways. Use milestones, deadlines, conferences and presentations for authentic professional practices.
Learning environment	-Tech and facility were a highlight -3 days for a project allowed for immersive learning experience -Need more hands-on activities	-High student satisfaction in facility and 3D printing technology -Short explanations and demonstrations for active students -Excellent maker space set up	-Set up a makerspace with a mix of high and low technology. Allow plenty of time for active learning and hands-on construction by keeping demonstrations and explanations short.

Criteria	Program 1: Tourism showcase	Program 2: Poverty inquiry	Key ideas for success from synthesis
Project Layer: Collective learning			
Team membership	-Allowed students to choose teams -Supported collaboration through specifically defined roles -Promoted individual expertise and accountability	-Scaffolds were provided to help students work well in teams -Time management strategies and visual organisers promoted input from all members	-Support teams to utilise individual expertise, manage time and be accountable for contributing. Defined roles, visual organisers and strategies can scaffold student collaboration as team members.
Diverse skills	-Regular reflection to consolidate skills and knowledge -scaffold problem-solving and Empathy and Define stages more	-Good use of investigating, researching and experimenting -Workshop on 3D printing and demonstration of laser cutting -Could promote more critical thinking about the student solutions	-Provide short workshops for learning new technologies. Scaffold fundamental skills such as critical thinking, problem solving, research, investigation, experimentation and reflection.
Tools enhance learning	-New technologies to excite students -Large touch-sensitive screens -Need trouble-shooting guides and video tutorials for problem-solving technologies	-Prior learning of theory at school allowed for time to use technology -Very high-quality prototypes -Need tech trouble shooting guides	-Use new technologies for interactive learning and high-quality prototypes. Resources to support teachers and students can include a digital booklet of the program for empathy, define and ideate stages and trouble-shooting videos/guide.
Project relationship to school & society	-Need to make stronger link to diverse professional pathways for aspiration -Link the project to learning at school for relevance	-Real world application of learning -Support for teachers trying new pedagogies and program design -Plans to embed the project in a school unit of work and present solutions to local industries	-Make explicit links to professions, school learning and real-world application of skills. Deepen the impact of the program by embedding the project in a school unit, presenting solutions to local industries and follow up support for teachers in program design and project-based pedagogies.

Appendix E. STEAM school unit planner of an interdisciplinary project mediated by a Tech School

Types of planning	Design thinking stages	Key pedagogical aspects	Subject/curriculum integration	Tech School involvement
1. Establish overarching topic for the unit		**Evaluation of learning**: Assessable outcomes related to prototype and presentation **Growth of capabilities**: Key transferable skills related to STEAM professions		Use Tech School-industry projects/competition for authenticity (eg. housing)
2. Plan unit with domain leaders from different subjects	**Enterprise**: Run a lesson/workshop on design thinking and local industries involved in housing design	**Student Agency/Personal connection**: Involve students in selecting project topics (eg. sustainability, sensor technology, innovative design features, Tiny houses, housing for vulnerable groups)	Map out main sub-domains to be covered from each subject	Tech School contacts industries for school support (eg. guest speakers, excursions, immersion day at Tech School and industry mentors)
3. Create term schedule	Map out the design stages over the term and which subjects will cover specific stages of the design thinking process	**Tools, Skills, Learning environment**: The students may need access to specific technologies, training, resources or a makerspace	Select content descriptors for each subject to be assessed and create a rubric to evaluate at key milestones of the project	Use Tech School templates of design thinking and rubrics that align projects with the Victorian or Australian Curriculum
4. Run the unit over 9 weeks. Weeks 1 and 2	**Empathy**: Introduce the unit, project themes, assessment rubric. Class interviews with industry/community group as an excursion or online meeting **Define**: Students form teams (2-4 students) based on their topic of interest. Conduct online research of example sites that incorporate sustainable housing, new technologies, housing designs. Consider social and environmental influence of housing	**Personal connection**: Relate the project to the students' interest in the topic and have some local examples of innovative architecture to visit **Growth of capabilities & differentiation**: Provide scaffolds for project management, research and an online shared-project folder with templates shared with teachers from each subject. This serves as a communication and resource sharing platform.	**Humanities-** Civics and citizenship: Housing for homeless and vulnerable **Personal and Social Capability**-Team management **Mathematics**: Find statistics on the issue **Digital Technologies**: Setting up online project management tools and skills **Science Understanding-** Science as a human endeavour: Relationship between science, technology and society	Tech School may coordinate the interviews between school and industry. This could also involve pre-recorded interviews exploring housing issues with a range of relevant industry and community groups
5. Weeks 3 and 4	**Ideate**: Student teams generate a variety of ideas and evaluate the most viable based on criteria. They also source ideas online. All resources are collated in a digital folder. **Prototype 1**: Students draw on paper and with software different designs, research and order suitable materials for a low-tech prototype	**Learning community**: Establish links across subjects so students and teachers are on-board with the project **Learning environment**: If the project is mostly online, having digital platforms that promote interactivity is essential **Team membership and skills:** provide scaffolds such as contracts, defined roles, protocols and agendas **Evaluation of learning:** have students submit work in a digital folio for formative assessment. Have a rubric to assess specific curriculum content for subjects (eg. Visual arts folio of ideas or technical drawings for design and technologies)	**Visual Arts**: sourcing and drawing ideas from nature and architecture **Design and technologies:** exploring design ideas and technologies **Digital technologies**: communicating ideas and collaborating online **Mathematics- Measurement and geometry**: Drawing 3D prisms **Capabilities**: embed critical and creative thinking in these subjects	Tech School may have useful project management software and resources to help teams to collaborate online. Digital technologies workshops could be conducted by the Tech School online or a short PD session for teachers and students at the Tech School or in the school

Types of planning	Design thinking stages	Key pedagogical aspects	Subject/curriculum integration	Tech School involvement
6. Weeks 5 and 6	**Prototype 2**: Student teams focus on building a prototype from recycled materials such as carboard, plastic bottles or have a digital prototype such as 3D design on Tinkercad or SketchUp **Test**: While students are not likely to be able to conduct an actual materials' test, they can write how part of a future prototype could be tested (eg. a test on insulation material like compressed straw). Alternative tests could involve receiving feedback from peers on prototypes based on set criteria	**Authentic practice**: Promote interdisciplinary processes involving measuring, aesthetic design, scientific research and testing. Have students work to a design brief with parameters or create their own brief with criteria for testing **Learning environment**: Use a designated makerspace, computer lab or art space depending on the type of prototype, with a range of tools and resources. Include manuals on construction and trouble-shooting guides for problem-solving technology and software **Tools and skills**: Include a range of low and high-tech tools. Depending on the type of prototype, split groups up for workshops on digital technology, manual construction or art	**Design and technologies**: producing designed solutions with tools and techniques **Science inquiry skills**: making testable predictions on materials (and if time conducting a test) **Mathematics-Number and algebra**: measuring and calculating materials, time and cost of prototype build **Visual arts**: Aesthetics and design **Media arts or Digital technologies**: Students may create a digital representation of their prototype in film, photoshop or Tinkercad	Tech School may lend technological resources and equipment for constructing and testing prototypes. Additional resources include online tutorials, help videos, design briefs and examples of high-quality design from industry. Industry mentors may be contacted to provide advice on making digital and physical prototypes
7. Week 7	**Prototype 3:** Students attend their local Tech School to iterate their original designs. This might involve exploring a specific aspect of their prototype such as installing sensors in their model houses or 3D printing/laser cutting features of a house. **Pitch/present**: Student teams present their prototypes and the development of their solution through the stages of the design thinking process	**Learning environment**: Students use the different spaces of the Tech School depending on the needs of the prototype **Tools:** A range of technologies are available for students with an emphasis on high-tech prototyping and presentation software **Skills:** short workshops to upskill students on prototyping technologies are provided **Authentic practice**: Make connections between the project and STEAM professions **Evaluation of learning**: Use the pitch presentation and prototypes as part of the summative assessment for the unit	**Science inquiry skills**: Using scientific concepts and terms to explain the design **Design and technologies-Technologies and society**: evaluating the choice of technologies and materials for the prototype **Media arts**: Using a range of media features in the pitch presentation	Utilise the Tech School for three days to produce a more high-tech or refined prototype. As the students have already worked through the design thinking cycle for their first prototypes, their experience of the Tech School can be focussed on exploring different technologies as well as presenting their prototypes out of the school environment
8. Weeks 8 and 9.	**Present:** Student work is presented in an online portfolio for each team. A summary and image of each prototype is displayed on the school website as a projects page. The link is shared with participating industries, parents and public. 2-minute recorded pitch presentations can be included as well. **Reflect:** Students complete group and individual reflections as summative assessment to demonstrate achievement and growth over the project	**Learning community**: Connect the project to the school community through the website **Project:** Have real-world connection to community and industry by inviting them to provide feedback comments on student work. This can involve a formal judging process if the project is a competition **Evaluation of learning:** Use an evaluation rubric for the project which assesses specific content for each subject as well as an interdisciplinary project assessment. **Growth of capabilities**: Reflection should focus on student learning of skills and knowledge through the design process rather than the final product	The final presentation of student work and reflections could include assessment for the following subjects **Science-Inquiry skills and understanding**: Content and method **Technologies- Design and digital technologies**: The design process and using a digital project platform **Visual arts and media arts**: Prototypes and presentations **Capabilities-Critical and creative thinking**: Metacognition **Personal and social capabilities**: project management and collaboration	Tech School can display some high-quality student prototypes on their website. This can be shared with participating industries and community groups. If these representatives judge specific projects to be of an outstanding standard or provide innovative solutions, schools can be contacted to offer follow up design programs for interested teams to move the project forward as a real solution

Appendix F: Curriculum aligned generic STEAM rubric

developed by the researcher, the director and the programs manager of a Tech School.

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Generic STEAM Project Assessment Rubric-Levels 9 & 10

Purpose

This rubric has been designed to support teacher assessment of student learning in STEAM units. Research on Tech School programs indicated that teachers wanted to use STEAM projects to assess against the Victorian curriculum standards for their subjects. The rubric is suitable for a stand-alone STE(A)M subject or ideally and interdisciplinary unit over a term. Please talk to your local Tech School for resources on how to embed Tech School projects and visits into your STEAM units at school.

Structure of the rubric

We have embedded the Victorian Curriculum standards into the stages of the Design Thinking Process used in Tech School projects. Subjects, standards and descriptors are listed for each stage of the Design Thinking Process where they are best suited. An assessment overview and marking sheet is included at the end of the rubric. Achievement levels out of 5 can be tallied in this table for an overall mark for the project or unit of work.

Levels from the Victorian Curriculum

This rubric is designed for students in Levels 9 & 10. We have other rubrics for Level 5 & 6 and 7 & 8 students. We have included in this rubric two descriptors from levels 7 & 8 Mathematics and one descriptor from levels 7 & 8 Science. This is because Level 9 & 10 Mathematics is too technically specialised for Tech School STEAM projects. The level 7& 8 descriptors are well suited to the prototyping stages of the project and allow for mathematics skills to be applied and assessed. This is the same for the Level 7 & 8 Science descriptor in the Test stage.

We encourage teachers of Mathematics and other subjects to tailor the rubric to incorporate specific subject content which is suited to their project. We have only included curriculum content which fits a generic Tech School STEAM project.

Explanation of terms

The rubric distinguishes between five levels of achievement with N indicating that no standards were met. The achievement levels are not equated with the continuum of curriculum levels. Rather they are an assessment of how well a student has demonstrated learning on a task, rather than the difficulty of the task achieved.

The five achievement levels are based on Bloom's Taxonomy of learning. An example of the main terms used is included below.

Achievement Level

5	**Outstanding:** The student researches, evaluates, improves and creates information
4	**Excellent:** The student researches, investigates, analyses and justifies information
3	**Established:** The student explores, explains, examines and discusses information
2	**Developing:** The student outlines, describes and summarises information
1	**Beginning:** The student recognises, identifies, selects and lists information
N	**Not Shown**

ENTERPRISE

Subject		Standard Category	Descriptor
Economics and Business		Enterprising behaviours and capabilities	Identify the ways enterprising behaviours and capabilities can be developed to improve the work and business environments
Standard		**Sub-Category**	
VCEBN027			
Achievement Level		**The student:**	
5	**Outstanding**	evaluates how different enterprising behaviours and capabilities can be improved in particular businesses or their own learning/work and develops a plan to do this with specific strategies	
4	**Excellent**	analyses how different enterprising behaviours and capabilities can be improved in particular businesses or their own learning/work and develops a plan to do this	
3	**Established**	explores how different types of enterprising behaviours and capabilities can be improved in particular businesses or their own learning/work	
2	**Developing**	summarises types of enterprising behaviours and capabilities and their importance for work, business and the economy	
1	**Beginning**	identifies enterprising behaviours and capabilities used for work	
N	**Not Shown**	has not reached a standard scribed in any of these proficiencies	

Subject		Standard Category	Descriptor
Economics and Business		Work and Work Futures	Research the way the work environment is changing in contemporary Australia and analyse the implications for current and future work
Standard		**Sub-Category**	
VCEBW025			
Achievement Level		**The student:**	
5	**Outstanding**	researches and evaluates different influences on the ways people work such as technology, globalisation and sustainability, the types of work available and predicts implications for future employment	
4	**Excellent**	researches different influences on the ways people work such as technology, globalisation and sustainability, the types of work available and predicts implications for future employment	
3	**Established**	explores different influences on the ways people work such as technology, globalisation and sustainability and the types of work available	
2	**Developing**	summarises influences on the ways people work such as technology, globalisation and sustainability	
1	**Beginning**	identifies influences on the ways people work such as technology, globalisation and sustainability	
N	**Not Shown**	has not reached a standard scribed in any of these proficiencies	

EMPATHISE

Subject		Standard Category	Descriptor
Design and Technologies		Creating Designed Solutions	Critique needs or opportunities to develop design briefs and investigate and select an increasingly sophisticated range of materials, systems, components, tools and equipment to develop design ideas
Standard		**Sub-Category**	
VCDSCD060		Investigating	
Achievement Level		**The student:**	
5	**Outstanding**	researches, analyses and evaluates the user's needs and evaluates the most suitable materials and technologies to design a sustainable solution	
4	**Excellent**	researches and analyses the user's needs and describes highly suitable materials and technologies to design a sustainable solution	
3	**Established**	explores the user's needs and outlines suitable materials and technologies to design a sustainable solution	
2	**Developing**	outlines the user's needs and lists suitable materials and technologies to design a sustainable solution	
1	**Beginning**	identifies a user's need and indicates materials that may be suitable to design a solution	
N	**Not Shown**	has not reached a standard scribed in any of these proficiencies	

EMPATHISE (CAPABILITIES)

Subject		Standard Category	Descriptor
Personal and Social Capability		Social Awareness and Management	Analyse how divergent values and beliefs contribute to different perspectives on social issues
Standard		**Sub-Category**	
VCPSCSO047		Relationships and diversity	
Achievement Level		**The student:**	
5	**Outstanding**	researches how a social issue impacts on the needs of a user from different perspectives and evaluates how personal values influence these different perspectives	
4	**Excellent**	researches how a social issue impacts on the needs of a user from different perspectives and possible reasons for differences in perspectives	
3	**Established**	explains how a social issue impacts on the needs of a user from different perspectives	
2	**Developing**	outlines how a social issue is relevant to the needs of a user	
1	**Beginning**	identifies a social issue relevant to the needs of a user	
N	**Not Shown**	has not reached a standard scribed in any of these proficiencies	

DEFINE

Subject		**Standard Category**	**Descriptor**
Science		Science Understanding	Advances in scientific understanding often rely on developments in technology and technological advances are often linked to scientific discoveries
Standard		**Sub-Category**	
VCSSU115		Science as a human endeavour	
Achievement Level		**The student:**	
5	**Outstanding**	researches and evaluates how the applications of technologies in different fields of science improves knowledge and predictability of phenomena in human and environmental systems	
4	**Excellent**	investigates how the applications of technologies in different fields of science improves knowledge of human and environmental systems	
3	**Established**	explores the applications of technologies on developments in different fields of science	
2	**Developing**	outlines the applications of technologies on developments in science	
1	**Beginning**	recognises that technology has influenced developments in science	
N	**Not Shown**	has not reached a standard scribed in any of these proficiencies	

Subject		**Standard Category**	**Descriptor**
Design and Technologies		Technologies and Society	Explain how designed solutions evolve with consideration of preferred futures and the impact of emerging technologies on design decisions
Standard		**Sub-Category**	
VCDSTS055			
Achievement Level		**The student:**	
5	**Outstanding**	researches, analyses and evaluates how technological change impacts on the basic needs of the user in a real-world context involving social, ethical and sustainability consequences at present and in future	
4	**Excellent**	researches and analyses how technological change impacts on the basic needs of the user in a real-world context involving social, ethical and sustainability consequences	
3	**Established**	examines how technological change impacts on the basic needs of the user in a real-world context	
2	**Developing**	outlines the basic needs of the user in a real-world context of technological change	
1	**Beginning**	identifies the basic needs of the user in a real-world context	
N	**Not Shown**	has not reached a standard scribed in any of these proficiencies	

Subject		**Standard Category**	**Descriptor**
Digital Technologies		Data and Information	Develop techniques for acquiring, storing and validating quantitative and qualitative data from a range of sources, considering privacy and security requirements
Standard		**Sub-Category**	
VCDTDI047			
Achievement Level		**The student:**	
5	**Outstanding**	develops strategies to securely store selected data from a range of sources in a useful digital format and evaluates their strengths and weaknesses	
4	**Excellent**	selects and securely stores data from a range of sources in a useful digital format and analyses their strengths and weaknesses	
3	**Established**	selects and stores data from a range of sources in a digital format and identifies their strengths and weaknesses	
2	**Developing**	acquires and compiles data into a digital format from a range of sources	
1	**Beginning**	acquires and compiles data into a digital format	
N	**Not Shown**	has not reached a standard scribed in any of these proficiencies	

Subject		**Standard Category**	**Descriptor**
Mathematics-Level 9		Statistics and Probability	Identify everyday questions and issues involving at least one numerical and at least one categorical variable, and collect data directly from secondary sources
Standard		**Sub-Category**	
VCMSP324		Data representation and interpretation	
Achievement Level		**The student:**	
5	**Outstanding**	Evaluates and applies a more suitable categorical variable to group numerical data from a secondary source	
4	**Excellent**	investigates whether a more suitable categorical variable can be selected to group numerical data from a secondary source	
3	**Established**	outlines the relevance to the user problem of the categorical variable used to group numerical data from a secondary source	
2	**Developing**	identifies the categorical variable (category feature) used to group numerical data from a secondary source relevant to the user problem	
1	**Beginning**	obtains numerical data from a secondary source such as the Australian Bureau of Statistics relevant to the user problem	
N	**Not Shown**	has not reached a standard scribed in any of these proficiencies	

DEFINE (CAPABILITIES)

Subject		Standard Category	Descriptor
Critical and Creative Thinking		Reasoning	Investigate use of additional or refined criteria when application of original criteria does not produce a clear conclusion
Standard		**Sub-Category**	
VCCCTR050			
Achievement Level		**The student:**	
5	**Outstanding**	through researched examples evaluates the clarity and precision of the problem statement based on the application of different criteria	
4	**Excellent**	examines the clarity and precision of the problem statement based on the strength of criteria used for definition	
3	**Established**	discusses how refining original criteria can improve their use in defining the problem	
2	**Developing**	outlines criteria characteristics of most use in defining the problem	
1	**Beginning**	identifies criteria for their usefulness in defining the problem	
N	**Not Shown**	has not reached a standard scribed in any of these proficiencies	

IDEATE

Subject		Standard Category	Descriptor
Science		Science Inquiry Skills	Formulate questions or hypotheses that can be investigated scientifically, including identification of independent, dependent and controlled variables
Standard		**Sub-Category**	
VCSIS134		Questioning and predicting	
Achievement Level		**The student:**	
5	**Outstanding**	evaluates using research how ideas for the prototype were revised based on available resources, information about the user and the problem identified	
4	**Excellent**	analyses and justifies how ideas for the prototype were revised based on available resources, information about the user and the problem identified	
3	**Established**	explains how ideas for the prototype were revised based on available resources and information about the user and the problem identified	
2	**Developing**	outlines ideas to develop the prototype based on available resources and information about the user	
1	**Beginning**	selects ideas for the prototype which can be developed with available resources	
N	**Not Shown**	has not reached a standard scribed in any of these proficiencies	

Subject		Standard Category	Descriptor
Design and Technologies		Creating Designed Solutions	Apply design thinking, creativity, innovation and enterprise skills to develop, modify and communicate design ideas of increasing sophistication
Standard		**Sub-Category**	
VCDSCD061		Generating	
Achievement Level		**The student:**	
5	**Outstanding**	evaluates the benefits and constraints of technology features in meeting criteria such as functionality, structure and aesthetics to make modifications to the design idea	
4	**Excellent**	analyses the benefits and constraints of technology features in meeting criteria such as functionality, structure and aesthetics in the design idea	
3	**Established**	explores how features of technologies can contribute to meeting criteria such as functionality, structure and aesthetics in the design idea	
2	**Developing**	describes how criteria such as functionality, structure and aesthetics have contributed to the design idea	
1	**Beginning**	identifies criteria such as functionality, structure and aesthetics in developing the design idea	
N	**Not Shown**	has not reached a standard scribed in any of these proficiencies	

IDEATE (CAPABILITIES)

Subject		Standard Category	Descriptor
Critical and Creative Thinking		Questions and Possibilities	Suspend judgements to allow new possibilities to emerge and investigate how this can broaden ideas and solutions
Standard		**Sub-Category**	
VCCCTQ044			
Achievement Level		**The student:**	
5	**Outstanding**	compares and evaluates a range of ideas using strategies such as suspending judgements, experimenting with technology and reflects on how the ideas have changed before selecting a final idea	
4	**Excellent**	investigates and compares a range of ideas using strategies such as suspending judgements and experimenting with technology before selecting a final idea	
3	**Established**	explores a range of ideas using strategies such as suspending judgements and experimenting with technology before selecting a final idea	
2	**Developing**	outlines a range of ideas before selecting a final idea	
1	**Beginning**	lists ideas before selecting a final idea	
N	**Not Shown**	has not reached a standard scribed in any of these proficiencies	

PROTOTYPE

Subject		**Standard Category**	**Descriptor**
Science		Science Inquiry Skills	Select and use appropriate equipment and technologies to systematically collect and record accurate and reliable data, and use repeat trials to improve accuracy, precision and reliability
Standard		**Sub-Category**	
VCSIS136		Planning and conducting	
Achievement Level		**The student:**	
5	**Outstanding**	improves specific skills applied to relevant equipment and technology to achieve intended results throughout the project, records this information and reflects on the improvements	
4	**Excellent**	applies specific skills relevant to equipment and technology used to achieve intended results, records this information and considers future improvements	
3	**Established**	applies specific skills relevant to equipment and technology used to achieve intended results and records this information	
2	**Developing**	applies specific skills relevant to equipment and technology used to achieve intended results	
1	**Beginning**	applies specific skills relevant to equipment and technology used	
N	**Not Shown**	has not reached a standard scribed in any of these proficiencies	

Subject		**Standard Category**	**Descriptor**
Design and Technologies		Creating Designed Solutions	Work flexibly to safely test, select, justify and use appropriate technologies and processes to make designed solutions
Standard		**Sub-Category**	
VCDSCD062		Producing	
Achievement Level		**The student:**	
5	**Outstanding**	safely, independently and innovatively manipulates technologies and materials to produce a high-quality prototype and considers alternatives to reduce waste or time	
4	**Excellent**	safely, independently and confidently manipulates technologies and materials to produce a high-quality prototype	
3	**Established**	safely and independently manipulates technologies and materials to produce a quality prototype	
2	**Developing**	safely manipulates technologies and materials to produce a prototype with assistance	
1	**Beginning**	safely manipulates technologies and materials with assistance	
N	**Not Shown**	has not reached a standard scribed in any of these proficiencies	

Subject		**Standard Category**	**Descriptor**
Digital technologies		Data and Information	Manage and collaboratively create interactive solutions for sharing ideas and information online, taking into account social contexts and legal responsibilities
Standard		**Sub-Category**	
VCDTDI049			
Achievement Level		**The student:**	
5	**Outstanding**	creates online interactive solutions to manage all aspects of the project and support group work by combining or modifying online software tools	
4	**Excellent**	sources online interactive solutions to manage all aspects of the project and support group work	
3	**Established**	manages aspects of the project such as sharing ideas and information online, applying established protocols, developing timelines and sequences for completing tasks on time	
2	**Developing**	applies established protocols to manage tasks such as backing-up, naming and storing files accessible to all team members	
1	**Beginning**	follows instructions for collaborative online group work	
N	**Not Shown**	has not reached a standard scribed in any of these proficiencies	

Subject		**Standard Category**	**Descriptor**
Mathematics-Level 7		Measurement and Geometry	Draw different views of prisms and solids formed from combinations of prisms
Standard		**Sub-Category**	
VCMMG260		Shape	
Achievement Level		**The student:**	
5	**Outstanding**	accurately sketches multiple designs of the structure of their prototype from different views and in parts with annotations such as dimensions and scale	
4	**Excellent**	accurately sketches the structure of the design of their prototype from multiple views or in parts with annotations such as dimensions and scale	
3	**Established**	accurately sketches the structure of the design of their prototype with annotations such as dimensions and scale	
2	**Developing**	sketches the structure of the design of their prototype with annotations such as dimensions and scale	
1	**Beginning**	provides a sketch of the design of their prototype	
N	**Not Shown**	has not reached a standard scribed in any of these proficiencies	

Subject		Standard Category	Descriptor
Mathematics-Level 8		Number and Algebra	Carry out the four operations with rational numbers and integers, using efficient mental and written strategies and appropriate digital technologies and make estimates for these computations
Standard		**Sub-Category**	
VCMNA273		Number and place value	
Achievement Level		**The student:**	
5	**Outstanding**	accurately estimates and calculates all factors related to the production or sale of the prototype such as the amount of material needed, production time, size or cost	
4	**Excellent**	estimates and calculates factors related to the production or sale of the prototype such as the amount of material needed, production time, size or cost	
3	**Established**	estimates factors related to the production or sale of the prototype such as the amount of material needed, production time, size or cost	
2	**Developing**	lists the factors related to the production or sale of the prototype such as the amount of material needed, production time, size or cost	
1	**Beginning**	identifies that factors such amount of material needed, production time, size or cost are relevant to the production of a prototype	
N	**Not Shown**	has not reached a standard scribed in any of these proficiencies	

TEST

Subject		Standard Category	Descriptor
Science-Level 7 & 8		Science Inquiry Skills	Construct and use a range of representations including graphs, keys and models to record and summarise data from students' own investigations and secondary sources, and to represent and analyse patterns and relationships
Standard		**Sub-Category**	
VCSIS110		Recording and processing	
Achievement Level		**The student:**	
5	**Outstanding**	collects and compares contrasting data from more than one source to test the prototype and create a summary of collected data to identify patterns and relationships	
4	**Excellent**	collects and compares contrasting data from more than one source to test the prototype and evaluate the summarised data	
3	**Established**	collects data from more than one source to test the prototype and create a summary of collected data	
2	**Developing**	collects and records data from more than one source to test the prototype	
1	**Beginning**	collects data to test the prototype	
N	**Not Shown**	has not reached a standard scribed in any of these proficiencies	

Subject		Standard Category	Descriptor
Science		Science Inquiry Skills	Use knowledge of scientific concepts to evaluate investigation conclusions, including assessing the approaches used to solve problems, critically analysing the validity of information obtained from primary and secondary sources, suggesting possible alternative explanations and describing specific ways to improve the quality of data
Standard		**Sub-Category**	
VCSIS139		Analysing and evaluating	
Achievement Level		**The student:**	
5	**Outstanding**	revises the test using a more scientific method either from primary or secondary sources of data to increase the validity of the conclusion	
4	**Excellent**	explores factors to increase the scientific validity of the test related to primary and secondary sources of data	
3	**Established**	outlines factors to increase the validity of the test from a scientific perspective for a more reliable conclusion	
2	**Developing**	describes how limitations of the test from a scientific perspective might account for different conclusions	
1	**Beginning**	identifies limitations of the test from a scientific perspective	
N	**Not Shown**	has not reached a standard scribed in any of these proficiencies	

Subject		Standard Category	Descriptor
Design and Technologies		Creating Designed Solutions	Evaluate design ideas, processes and solutions against comprehensive criteria for success recognising the need for sustainability
Standard		**Sub-Category**	
VCDSCD063		Evaluating	
Achievement Level		**The student:**	
5	**Outstanding**	tests and evaluates the success of their designed solution or prototype according to specific criteria including functionality and sustainability, and makes changes to their design and processes used through iteration	
4	**Excellent**	tests and justifies the success of their designed solution or prototype according to specific criteria, including functionality and sustainability, and details changes which should be made to the design or processes used	
3	**Established**	tests and assesses the success of their designed solution or prototype according to specific criteria and explains changes which should be made to the design or process used	
2	**Developing**	tests and assesses the success of their designed solution or prototype according to specific criteria	
1	**Beginning**	tests their designed solution or prototype according to basic criteria	
N	**Not Shown**	has not reached a standard scribed in any of these proficiencies	

COMMUNICATE/PITCH

<table>
<tr><th colspan="2">Subject</th><th>Standard Category</th><th>Descriptor</th></tr>
<tr><td colspan="2">Science</td><td>Science Inquiry Skills</td><td rowspan="4">Communicate scientific ideas and information for a particular purpose, including constructing evidence-based arguments and using appropriate scientific language, conventions and representations</td></tr>
<tr><th colspan="2">Standard</th><th>Sub-Category</th></tr>
<tr><td colspan="2">VCSIS140</td><td>Communicating</td></tr>
<tr><th colspan="2">Achievement Level</th><th colspan="2">The student:</th></tr>
<tr><td>5</td><td>Outstanding</td><td colspan="2">evaluates with evidence the designed solution using a range of representations, design thinking and scientific concepts including impacts and limitations of the solution</td></tr>
<tr><td>4</td><td>Excellent</td><td colspan="2">justifies with evidence the designed solution using a range of representations, design thinking and scientific concepts</td></tr>
<tr><td>3</td><td>Established</td><td colspan="2">explains the designed solution using a range of representations, design thinking or scientific language</td></tr>
<tr><td>2</td><td>Developing</td><td colspan="2">outlines the designed solution using representations and appropriate language</td></tr>
<tr><td>1</td><td>Beginning</td><td colspan="2">presents the designed solution</td></tr>
<tr><td>N</td><td>Not Shown</td><td colspan="2">has not reached a standard scribed in any of these proficiencies</td></tr>
</table>

<table>
<tr><th colspan="2">Subject</th><th>Standard Category</th><th>Descriptor</th></tr>
<tr><td colspan="2">Design and Technologies</td><td>Technologies and Society</td><td rowspan="3">Critically analyse factors, including social, ethical and sustainability considerations, that impact on designed solutions for global preferred futures and the complex design and production processes involved</td></tr>
<tr><th colspan="2">Standard</th><th>Sub-Category</th></tr>
<tr><td colspan="2">VCDSTS054</td><td></td></tr>
<tr><th colspan="2">Achievement Level</th><th colspan="2">The student:</th></tr>
<tr><td>5</td><td>Outstanding</td><td colspan="2">evaluates how the choice of technologies, materials and concept for their design solves the user’s problem and contributes to a preferred future with evidence from research on ethics and sustainability</td></tr>
<tr><td>4</td><td>Excellent</td><td colspan="2">justifies how the choice of technologies, materials and concept for their design solves the user’s problem and contributes to a preferred future based on ethics and sustainability</td></tr>
<tr><td>3</td><td>Established</td><td colspan="2">explains how the choice of technologies, materials and concept for their design solves the user’s problem and contributes to a preferred future</td></tr>
<tr><td>2</td><td>Developing</td><td colspan="2">outlines how the choice of technologies, materials and concept for their design solves the user’s problem</td></tr>
<tr><td>1</td><td>Beginning</td><td colspan="2">presents the user’s problem and their designed solution</td></tr>
<tr><td>N</td><td>Not Shown</td><td colspan="2">has not reached a standard scribed in any of these proficiencies</td></tr>
</table>

<table>
<tr><th colspan="2">Subject</th><th>Standard Category</th><th>Descriptor</th></tr>
<tr><td colspan="2">Media Arts</td><td>Media Arts Practices</td><td rowspan="3">Develop and refine media production skills to integrate and shape the technical and symbolic elements in images, sounds and text to represent a story, purpose, meaning and style</td></tr>
<tr><th colspan="2">Standard</th><th>Sub-Category</th></tr>
<tr><td colspan="2">VCAMAM042</td><td></td></tr>
<tr><th colspan="2">Achievement Level</th><th colspan="2">The student:</th></tr>
<tr><td>5</td><td>Outstanding</td><td colspan="2">collaboratively and creatively utilises diverse production skills to convey meaning, purpose and style in the pitch presentation by engaging the interests of a specific audience</td></tr>
<tr><td>4</td><td>Excellent</td><td colspan="2">collaboratively and confidently utilises production skills to convey meaning, purpose and style in the pitch presentation to engage the audience</td></tr>
<tr><td>3</td><td>Established</td><td colspan="2">collaboratively and effectively utilises production skills to convey meaning and purpose in the pitch presentation</td></tr>
<tr><td>2</td><td>Developing</td><td colspan="2">utilises production skills to enhance the pitch presentation</td></tr>
<tr><td>1</td><td>Beginning</td><td colspan="2">presents a pitch using suitable media</td></tr>
<tr><td>N</td><td>Not Shown</td><td colspan="2">has not reached a standard scribed in any of these proficiencies</td></tr>
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REFLECT

<table>
<tr><th colspan="2">Subject</th><th>Standard Category</th><th>Descriptor</th></tr>
<tr><td colspan="2">Science</td><td>Science Understanding</td><td rowspan="3">The values and needs of contemporary society can influence the focus of scientific research</td></tr>
<tr><th colspan="2">Standard</th><th>Sub-Category</th></tr>
<tr><td colspan="2">VCSSU116</td><td>Science as a human endeavour</td></tr>
<tr><th colspan="2">Achievement Level</th><th colspan="2">The student:</th></tr>
<tr><td>5</td><td>Outstanding</td><td colspan="2">evaluates how their own further research into the user problem can promote social action or change business and government policies regarding the user problem</td></tr>
<tr><td>4</td><td>Excellent</td><td colspan="2">investigates how further research in the field can promote social action or change business and government policies regarding the user problem</td></tr>
<tr><td>3</td><td>Established</td><td colspan="2">describes how research into the user problem has influenced their own view of the problem, can influence social views of the problem as well as further research in the field</td></tr>
<tr><td>2</td><td>Developing</td><td colspan="2">outlines how research into the user problem has influenced their own view of the problem and can influence social views of the problem</td></tr>
<tr><td>1</td><td>Beginning</td><td colspan="2">identifies how research into the user problem has influenced their own view of the problem</td></tr>
<tr><td>N</td><td>Not Shown</td><td colspan="2">has not reached a standard scribed in any of these proficiencies</td></tr>
</table>

<table>
<tr><th colspan="2">Subject</th><th>Standard Category</th><th>Descriptor</th></tr>
<tr><td colspan="2">Visual Communication Design</td><td>Present and Perform</td><td rowspan="4">Develop a brief that identifies a specific audience and needs, and present visual communications that meet the brief</td></tr>
<tr><th colspan="2">Standard</th><th>Sub-Category</th></tr>
<tr><td colspan="2">VCAVCDP009</td><td></td></tr>
<tr><th colspan="2">Achievement Level</th><th colspan="2">The student:</th></tr>
<tr><td>5</td><td>Outstanding</td><td colspan="2">evaluates with examples the selection of design elements, principles, materials and media to communicate ideas to a target audience, meet the design brief and evaluates improvements to be made to the pitch</td></tr>
<tr><td>4</td><td>Excellent</td><td colspan="2">justifies with examples the selection of design elements, principles, materials and media to communicate ideas to a target audience and meet the design brief for the pitch</td></tr>
<tr><td>3</td><td>Established</td><td colspan="2">explains decisions made in selecting design elements, principles, materials and media used to communicate ideas to a target audience and meet the design brief for the pitch</td></tr>
<tr><td>2</td><td>Developing</td><td colspan="2">summarises decisions made in selecting design elements, principles, materials and media used to communicate ideas to a target audience</td></tr>
<tr><td>1</td><td>Beginning</td><td colspan="2">identifies media elements used to communicate ideas to a target audience</td></tr>
<tr><td>N</td><td>Not Shown</td><td colspan="2">has not reached a standard scribed in any of these proficiencies</td></tr>
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REFLECT (CAPABILITIES)

<table>
<tr><th colspan="2">Subject</th><th>Standard Category</th><th>Descriptor</th></tr>
<tr><td colspan="2">Critical and Creative Thinking</td><td>Meta-Cognition</td><td rowspan="4">Investigate the kind of criteria that can be used to rationally evaluate the quality of ideas and proposals, including the qualities of viability and workability</td></tr>
<tr><th colspan="2">Standard</th><th>Sub-Category</th></tr>
<tr><td colspan="2">VCCCTM053</td><td></td></tr>
<tr><th colspan="2">Achievement Level</th><th colspan="2">The student:</th></tr>
<tr><td>5</td><td>Outstanding</td><td colspan="2">evaluates how workability and viability of the designed solution can be improved based on an assessment of its practical implementation and risks involved against criteria</td></tr>
<tr><td>4</td><td>Excellent</td><td colspan="2">analyses whether the designed solution is workable and viable against criteria for practical implementation and risks involved</td></tr>
<tr><td>3</td><td>Established</td><td colspan="2">explains the workability and viability of the designed solution against criteria for practical implementation and risks involved</td></tr>
<tr><td>2</td><td>Developing</td><td colspan="2">outlines the workability of the designed solution against criteria for practical implementation</td></tr>
<tr><td>1</td><td>Beginning</td><td colspan="2">identifies factors relevant to the workability of the designed solution</td></tr>
<tr><td>N</td><td>Not Shown</td><td colspan="2">has not reached a standard scribed in any of these proficiencies</td></tr>
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<table>
<tr><th colspan="2">Subject</th><th>Standard Category</th><th>Descriptor</th></tr>
<tr><td colspan="2">Personal and Social Capability</td><td>Social Awareness and Management</td><td rowspan="4">Evaluate own and others contribution to group tasks, critiquing roles including leadership and provide useful feedback to peers, evaluate task achievement and make recommendations for improvements in relation to team goals</td></tr>
<tr><th colspan="2">Standard</th><th>Sub-Category</th></tr>
<tr><td colspan="2">VCPSCSO050</td><td>Collaboration</td></tr>
<tr><th colspan="2">Achievement Level</th><th colspan="2">The student:</th></tr>
<tr><td>5</td><td>Outstanding</td><td colspan="2">evaluates how improving the clarity of roles and the division of the tasks would improve the overall success of the project with specific examples and suggests strategies as feedback to team members</td></tr>
<tr><td>4</td><td>Excellent</td><td colspan="2">analyses how improving the clarity of roles and the division of the tasks would improve the overall success of the project with specific examples</td></tr>
<tr><td>3</td><td>Established</td><td colspan="2">explains how improving the clarity of roles and the division of the tasks would improve the overall success of the project</td></tr>
<tr><td>2</td><td>Developing</td><td colspan="2">outlines the relative contribution of team members to the overall completion of the project</td></tr>
<tr><td>1</td><td>Beginning</td><td colspan="2">identifies the roles that team members undertook</td></tr>
<tr><td>N</td><td>Not Shown</td><td colspan="2">has not reached a standard scribed in any of these proficiencies</td></tr>
</table>

SPARE TEMPLATES FOR ADDITONAL STANDARDS

<table>
<tr><th colspan="2">Subject</th><th>Standard Category</th><th>Descriptor</th></tr>
<tr><td colspan="2"></td><td></td><td rowspan="4"></td></tr>
<tr><th colspan="2">Standard</th><th>Sub-Category</th></tr>
<tr><td colspan="2"></td><td></td></tr>
<tr><th colspan="2">Achievement Level</th><th colspan="2">The student:</th></tr>
<tr><td>5</td><td>Outstanding</td><td colspan="2"></td></tr>
<tr><td>4</td><td>Excellent</td><td colspan="2"></td></tr>
<tr><td>3</td><td>Established</td><td colspan="2"></td></tr>
<tr><td>2</td><td>Developing</td><td colspan="2"></td></tr>
<tr><td>1</td><td>Beginning</td><td colspan="2"></td></tr>
<tr><td>N</td><td>Not Shown</td><td colspan="2"></td></tr>
</table>

Assessment plan for generic STEAM rubric- Levels 9 & 10 of the Victorian Curriculum.

Project name: **Student name:** **Team name:**

PROJECT STAGE	SCIENCE	TECHNOLOGIES	THE ARTS	THE HUMANITIES	MATHEMATICS	CAPABILITIES
ENTERPRISE				Economics and Business VCEBN027 /5 VCEBW025 /5		
EMPATHISE		Design and Technologies VCDSCD060 /5				Personal and Social Capability VCPSCSO047 /5
DEFINE	Science VCSSU115 /5	Design and Technologies VCDSTS055 /5 Digital Technologies VCDTDI047 /5			Mathematics-Level 9 VCMSP324 /5	Critical and Creative Thinking VCCCTR050 /5
IDEATE	Science VCSIS134 /5	Design and Technologies VCDSCD061 /5				Critical and Creative Thinking VCCCTQ044 /5
PROTOTYPE	Science VCSIS136 /5	Design and Technologies VCDSCD062 /5 Digital technologies VCDTDI049 /5			Mathematics-Level 7 VCMMG260 /5 Mathematics-Level 8 VCMNA273 /5	
TEST	Science-Level 7 & 8 VCSIS110 /5 Science-Level 9 & 10 VCSIS139 /5	Design and Technologies VCDSCD063 /5				
COMMUNICATE/ PITCH	Science VCSIS140 /5	Design and Technologies VCDSTS054 /5	Media Arts VCAMAM042 /5			
REFLECT	Science VCSSU116 /5		Visual Communication Design VCAVCDP009 /5			Critical and Creative Thinking VCCCTM053 /5 Personal and Social Capability VCPSCSO050 /5
Total Marks	/35	/40	/10	/10	/15	/25

COMMENTS:

Appendix G: Full journal article for case study 2
Integrating STEAM Through Design Thinking

Abstract

The purpose of this paper is to illustrate the use of a Tech School design thinking process for structuring industry and community-focussed STEAM projects. A qualitative case study of a secondary school STEAM festival provides an example of a transdisciplinary housing project using design thinking. Observations of the festival are analysed with reference to STEAM and design thinking literature. Interviews with participating teachers and students provide insight into the opportunities of using design thinking for project-based learning. The principal finding of the study is that the design thinking process is an effective and engaging means of structuring a project. Yet, by embedding the curriculum into the design thinking process, student learning in projects could be enhanced. A table embedding the Australian Curriculum learning areas and general capabilities into the design thinking process is provided as a resource for teachers wanting to connect STEAM projects to the curriculum. An additional resource is the utilisation of Tech Schools in Victoria to support schools making the shift from transdisciplinary to interdisciplinary STEAM. The conclusion is that project-based STEAM will have more impact if it is integrated into subjects as an interdisciplinary unit, rather than as a transdisciplinary festival.

Keywords: STEAM, Tech Schools, Design Thinking, Australian Curriculum, Interdisciplinary Learning, Secondary Schools

Authentic STEAM projects to connect learning, curriculum and industry

The compartmentalisation of learning into separate subjects has created issues regarding overspecialisation, which is not suited to the interrelated problems and opportunities of the twenty-first century. STEAM represents one way of breaking down subject silos through authentic interdisciplinary projects to solve complex real-world problems. Whether one chooses STEM or STEAM, interdisciplinary projects can be used to make meaningful connections between learning areas from the Australian Curriculum, promote teacher collaboration and foster partnerships with the community and local industries (Australian Curriculum and Assessment Reporting Authority, 2016; Australian Industry Group, 2017). These partnerships broaden the network that students can access for applying their skills and knowledge in a broader social context.

A case study of a STEAM festival project, based on a Tech School design thinking model is presented in this paper. Examples of how content from each subject can be embedded into projects for assessment are included for teachers who wish to make STEAM integral to the curriculum rather than co-curricular. By making specific connections to the Australian Curriculum, this paper addresses the issue that 'there are no stand-alone places to report interdisciplinary learning' (MacDonald, Hunter, Wise, & Fraser, 2019, p. 87). By highlighting suitable descriptors from the curriculum, disciplinary learning can be reported on at key stages of the design thinking process while being taught in an interdisciplinary manner. In this way, project-based learning becomes a more authentic and effective means of delivering the curriculum by relating key concepts that run across learning areas such as science, technologies, humanities and the arts.

Why STEAM instead of STEM?

Putting the A—which stands for the creative arts and the humanities—in STEM, addresses the social capabilities needed and the interdisciplinary nature of work in the twenty-first century. Due to the changing nature of work through the impact of technology, increasing Australian students' interest and performance in science, technology, engineering and mathematics (STEM) has been considered essential for Australia's industry and innovation economy (Office of the Chief Scientist, 2016). Yet, developing technical skills relevant to STEM will only partly prepare Australia's workforce for technological changes to industry. According to the Foundation for Young Australians, employees need to have a set of transferrable 'enterprise skills' to continuously adapt to rapid changes in—and across—industries (2017b, p.8). These enterprise skills which include critical and creative thinking, teamwork, presentation skills and communication are essential to the high-growth job sector of community and personal services (Foundation for Young Australians, 2017a). Employers not only value technical expertise in STEM, they also value personal and social capabilities developed in the humanities and the arts, referred to as 'liquid skills' (Taylor, 2016, p. 90).

Authentic STEAM projects can foster student interest in science and mathematics subjects and foster enterprising capabilities for innovation without funnelling students through a STEM 'pipeline' (Colucci-Gray, Burnard, Gray, & Cooke, 2019, p. 2). STEAM in schools is a collaborative approach to integrating the curriculum from different learning areas through the exploration of common themes that bridge the divide between STEM (science, technology, engineering, mathematics) and HASS (humanities, arts, social sciences). Dividing STEM and HASS creates a false dichotomy in terms of how knowledge is generated and how contemporary industry operates (Cunningham, 2007). This claim will be substantiated by briefly presenting why the arts and the humanities are fundamental to industry and education—and why STEM needs to become STEAM.

Creative arts infuse STEM with subjectivity for innovation

Industries which better understand human needs prosper, by orientating product design and technology towards increasing user satisfaction (Knight, 2011). Human-centred design is central to high growth industries such as 'medical technology and pharmaceuticals, transport, international education and professional services' (State of Victoria Department of Education and Training, 2016, p. 3).

In schools, the arts foster creativity needed for innovation by promoting the act of looking with an open mind and exploring our subjective relationships with the world. As Eisner (2002) and previously Dewey (1959) note that the arts promote the act of perception which is an aesthetic experience. Cultivating aesthetic sensibilities is not only crucial for personal development, aesthetic awareness also underpins innovative design through improved tools and technologies which satisfy personal needs and elevate daily experiences of the world (Harris & De Bruin, 2017).

The humanities bring criticality for ethical progress in STEM

Reconceptualising industry as serving an ethical and social role encourages alternative means of production as well as more sustainable ends. International examples include sustainable fashion (Gardetti & Torres, 2013), eco-factories (Kurle, Thiede, & Herrmann, 2019) and organic food production (Belz & Schmidt-Riediger, 2010). Within the State of Victoria, 'new energy technologies', and 'food and fibre' are growing industries which will benefit from workers with a range of STEAM skills for developing innovative solutions (State of Victoria Department of Education and Training, 2016, p. 3).

In schools, the humanities allow for a broader perspective of industry in promoting discussions about ethics, empathy and sustainability. Industrial applications of science and technology have potential societal benefits if carefully monitored, yet ethical issues need to be considered. Contemporary examples include biased software algorithms, unforeseeable effects of germ-line editing and high-scale geoengineering (Lachman 2018). Developing a critical awareness of the moral purpose of progress requires making ethical judgements about 'whether we ought to be doing all the things that science and technology now allow us to do' (Winston & Edelbach, 2014, p. xiii).

What STEAM brings to twenty-first century education

The case being made for STEAM education is a pragmatic one. Industry is increasingly becoming interdisciplinary with the line between STEM and HASS becoming blurred. Education has a crucial role in helping young people to draw on all their available knowledge and skills to creatively design solutions to complex issues which have technological and social dimensions (Boy, 2013; Guyotte, Sochacka, Costantino, Walther, & Kellam, 2014). Incorporating the arts and humanities into STEM allows for a synthesis of specialised skills and general capabilities to creatively design solutions as well as identifying where distinctions are needed between ethical and unethical solutions (Burnard, & Colucci-Gray, 2020). Determining where a fusion or a disentanglement of disciplinary perspectives is needed, reflects a critical tension in cross-disciplinary education relative to the aims and scope of the Australian curriculum (MacDonald, et al., 2019). This requires ongoing examination by teachers and curriculum leaders in schools.

Approaches to STEAM Integration

STEAM like STEM can be implemented through multidisciplinary, transdisciplinary or interdisciplinary models (Herro & Quigley, 2017; Vasquez, Sneider, & Comer, 2013). For project-based learning where arts play a central role, a *transdisciplinary* approach is popular (Costantino, 2018; Guyotte et al., 2014; Liao, 2016). While transdisciplinary projects are adaptable to student interest which promotes engagement, the project may not allow for assessment or reporting against curriculum (Herro & Quigley, 2017). An *interdisciplinary* approach allows for subject curriculum to be integrated into the project to foster collaboration between teachers and add formal assessment of learning. Yet, it requires a deeper level of integration into the school structure which can be disruptive to traditional timetabling in subject silos (Thomas & Huffman, 2020).

According to MacDonald et al., overcoming the rigidity of disciplinary boundaries in Australian schools can be supported through the exploration of the 'spaces between' learning areas (2019, p. 37). In addition to the space *between*, STEAM supports development of general capabilities *across* learning areas of the Australian Curriculum, which Taylor (2016) considers crucial for meeting the opportunities and challenges of the twenty-first century. Critical and creative thinking, ethical and intercultural understandings, personal and social capabilities from the Australian Curriculum can be fostered through STEAM, as well as providing a cultural entry point for exploring the cross-curriculum priorities. In this way, STEAM can provide a platform for meaningfully relating the three dimensions of the F-10 Australian Curriculum: learning areas, general capabilities and cross-curriculum priorities (Australian Curriculum, Assessment and Reporting Authority, 2020b). This is important for accommodating to the diverse interests and needs and students and for providing teachers with a structured approach to planning units with overarching cross-disciplinary themes.

STEAM can provide an authentic cultural platform for relating the cross-curriculum priorities to learning areas such as science and technologies. These include learning about Aboriginal and Torres Strait Islander histories and cultures, Australia's engagement with Asia, and sustainability (Australian Curriculum and Assessment Reporting Authority, 2020a). An example of fostering an appreciation for science within a cultural context is presented by Chu, Martin, and Park (2019). Based on the 5E instructional model by Bybee (2015), the authors provide a case study of an intercultural STEAM unit involving collaboration between Australian and Korean schools.

In contrast to this example of a STEAM unit using the 5E model of *inquiry*, this paper will provide an example of STEAM for promoting engagement with industry and community through *solutions design*. It draws on the design thinking model developed by the Stanford d.school and adapted by Tech Schools in Victoria (Hasso Plattner Institute of Design at Stanford). While secondary education shouldn't be solely about developing work skills, engagement with industry and community projects does provide a necessary connection between school and the world. According to Baxter (2017) having authentic experiences related to careers promotes student engagement and fosters aspiration, especially for students who lack academic skills, motivation or come from a background of poverty. A need to foster aspiration in industry has prompted the construction of Tech School initiative in regional Victorian cities. Tech School STEAM projects can foster meaningful connections between school learning, community and industry. A brief introduction to Tech Schools is now provided.

Tech Schools: Transdisciplinary STEAM projects

Between 2017 and 2019, the state government built 10 Tech Schools in Victoria, Australia. Many Tech Schools are developing STEAM programs using a design thinking model to promote problem solving through real world projects. Tech School projects are based on community and industry issues which fit within the DET Industry foci (State of Victoria Department of Education and Training, 2019). Tech Schools promote human-centred design which uses empathy for the user as a starting point, to inform subsequent stages of iteration (IDEO, 2011). For a comprehensive outline of the pedagogical, physical and conceptual context of Tech Schools, refer to Sacrez (2020).

Based on the 5-stage Stanford d.school model of design thinking (Hasso Plattner Institute of Design at Stanford), Tech School projects direct students through seven stages of an iterative design cycle. Table 1 outlines the seven stages of design thinking used in a number of Tech Schools.

Design Thinking Stages	Student activities
Empathise	Collecting information about the user and the problem to be solved
Define	Creating a problem statement based on the user's needs
Ideate	Group brainstorming to generate diverse and creative solutions
Prototype	Constructing a physical representation to help conceptualise the solution
Test	Sharing the prototype with the user to gain feedback for modification/redesign
Pitch	Communicating to an audience the value of the designed solution
Reflect	Discussing failures and successes to reinforce collective learning

Table 1. *The design thinking process commonly used in Tech School programs*

These seven stages structure Tech School programs into a sequence, with opportunities for repeating parts, or the whole cycle to refine projects through iteration. The use of the design thinking process for designing and teaching a STEAM program will now be examined through a case study.

Four-day STEAM festival: Case study design

This paper presents a case study on a STEAM festival run in a public secondary school in Victoria which used the design thinking process to structure student projects. This case study was part of a three-year research project on the role of Tech Schools in supporting the development of STEAM programs in secondary schools (Ethics ID: HEC19012).

The case study will first present researcher observations and interviews with five students and four teachers involved in the STEAM festival to highlight key insights related to opportunities and limitations of running a co-curriculum STEAM event. Participant interviews were triangulated with observation recordings and thematically analysed to elicit key insights which included *student agency*, *integration/interdisciplinarity* and *authenticity*. The theme of interdisciplinarity is elaborated by considering how specific links to the Australian Curriculum could be made in each stage of the design thinking process. This is summarised in a table as a resource for teachers undertaking industry/community-based STEAM projects. Finally, the analysed findings are evaluated with reference to the literature on building authentic connections between STEAM projects, industry/community and the Australian Curriculum with support from Tech Schools.

Case study findings of the four-day STEAM festival

The festival was held in the last week of term in a regional 7-10 secondary school in Victoria. The four-day festival was a whole school event involving all Year 7, 8 and 9 students (approximately 500 students). Year 10 students were away on work-experience. During the festival, usual classes were suspended. The case study focussed on a group of 60 students from one of the four school communities, who undertook a housing project. This small case study is presented because it is an example of a low-stakes approach to transdisciplinary STEAM, using a design thinking process which other schools could implement. It also represents typical limitations of time and assessment of projects in transdisciplinary projects (Herro & Quigley, 2017). Proposed solutions to the issues raised in the case study are provided in the analysis as scaffold for teachers embarking on interdisciplinary STEAM projects.

Teacher planning for the festival

Two weeks prior to the festival, teachers from science, mathematics, English, the humanities, technology and the arts met three times to map out the logistics of running the project. These planning meetings allowed teachers from different domains to work and learn together which one teacher described as a rare opportunity. The four-day housing project was a version of a program run in the local Tech School. This provided the teachers with a project which had already been tested with different groups of students as well as templates on the design thinking process.

Interviewed teachers valued the meaningful learning experiences that interdisciplinary STEAM projects created for the students through real world connections to industry and community,

> That is the point of it anyway, that when you go into any industry, you work across. You don't just work in any one area. Which is another argument for why we have had to move away from STEM into STEAM, because when we were just teaching STEM to get a better PISA rate the cracks were starting to show (Arts teacher).

The festival was seen by some teachers as a trial for developing an integrated program embedded into the school timetable involving interdisciplinary collaboration between teachers.

> We can easily marry English and the humanities together or maths and science together and set them off on their ways and get them to team-teach. But we are not actually doing a true integrated program. We're not really representing industry or what really happens in a workplace (Arts teacher).

The potential for increasing student engagement through integration was also mentioned

> I think we need a more balanced curriculum here. I think we are too maths heavy. We have double the time in Maths and English compared to any other subject. But they are not usually the engagement subjects, why students are here. Students come to school to learn English and Maths because they are told it is important but it doesn't keep them entertained (Mathematics and science teacher).

Translating a festival into an integrated unit was seen as posing some logistical challenges,

> It is one of those things that is always talked about, those integrated units. it is easy to do it with a small group of kids. But we want it to be equitable, so the challenge is when we have 250 Year 7 kids who are all working through a sustainability project (Music, humanities and digital technologies teacher).

These and other comments by the teachers suggested that the STEAM festival was seen as a step towards delivering a more integrated curriculum until the school leaders were ready to make structural changes to the timetable.

Day 1: Empathise and Define

Groups of two to three students undertook a range of brainstorming activities on affordability, homelessness and sustainability to explore the topic of housing. For one group of students this was a powerful connection,

> We came up with the idea of building a unit to help single parents and their children in need as they don't always have the money or things to cope. My mum is a single parent. I kind of thought she has a lot of stress to try and put shelter over us. So, it would be a lot easier for other single parents who are in a worse position than us to have some kind of shelter until they can get on their feet and try and find a place (Year 8 student).

This student comment demonstrates how a project can empower students to reflect on personal issues and generalise to other members of the community through empathy. These personal student connections were then related to the ethical issue of social housing by having a guest speaker present on the issue of homelessness in Australia. The students researched statistics related to the issue of homelessness and different eco-friendly building options to create a defining statement of the issue for an individual member or members of the local community.

From a curriculum perspective, asking the students to consider social and environmental issues in defining their user problem provided opportunities for drawing on the general capabilities such as the personal and social capability, ethical understanding as well as the cross-curriculum priority of sustainability. The students were given a booklet to record their ideas and to write a defining statement of the problem. Unfortunately, the booklet did not contribute to students' school report.

One teacher felt that sustainable housing was a topic that fostered connections between the arts and humanities and STEM and would be well suited to an integrated unit using the design thinking process

> Sustainability is a unit of work where the humanities are looking at climate and urbanisation. So, housing and sustainability come under that umbrella. In the Empathise phase, researching and understanding the problem. Applying what we know about insulation from research to the project as a prototype is really important and the humanities come through in that. And art as well follows that design process really well (Music, humanities and digital technologies teacher).

Day 2: Ideate and Prototype

On the second day of the festival, the students visited a factory which makes sustainable Tiny Houses using compressed straw panels. The students toured the display yard where the Tiny Houses were assembled and asked questions about the design process, construction, cost and the sustainability of the materials used. This provided a tangible example of an innovative housing business.

Back at school, the students undertook an *Ideation* session, by generating as many novel ideas as possible, recording them on sticky notes and displaying them on a section of a wall. This interactive visualisation technique was followed by a process of synthesising and selecting the most innovative ideas to solve the user problem, while also ensuring a prototype could be built over the next two days. The opportunity for teachers to observe the students collaborating and independently problem solving was considered valuable by the teachers,

> I think the real plus is seeing kids working together. Having conversations. It is one thing to go up and ask a question, but just walking past and listening is powerful. To hear them in their own 'kids-speak' (English teacher).

Day 3: Prototyping

Some groups of students began prototyping at the end of the second day. Other groups started on the third day. Prior to prototyping, the teachers reviewed the students' STEAM booklets and discussed their idea as formative assessment. Student prototypes included models of Tiny Houses, camper vans with solar panels, community housing for the homeless, and a variety of eco-friendly homes. Materials used were recycled cardboard, paint and ice cream sticks connected with hot glue. Most students were enthusiastic about having the freedom to create, although some students lacked confidence in their ability to construct.

Day 4: Test, Present and Reflect

The final day of the festival commenced with students completing the prototypes and the booklets. The other half of the day involved presenting the work and reflecting on the project. Part of the presentation of work involved annotating the prototypes with descriptions of key features related to solving the problem. The prototypes were displayed in a large learning space with other school community projects in preparation for the next day's parent-teacher interviews.

Each group briefly explained their prototype to the rest of the community. Student feedback was given to groups verbally or written down on a form accompanying the prototype. Due to a lack of time, there was no redesign or iteration based on this feedback. The festival was completed with a whole community reflection on the challenges and successes of the projects.

Interviewed students shared insights on key themes from the festival. One common theme was the promotion of student agency and autonomy of learning through projects,

> Something that I learned personally was how to come up with a topic and then to branch out from that and get different ideas from it. It is important to know that you can do the project in many different ways (Year 8 student).
>
> It allows us to develop at our own pace and reflect on our own skills. And of course, the support would still be there but we can work without relying on people and the teachers so much (Year 8 student).

The social benefit of working with friends was also a common theme 'It was good to do it over a period of time with people you feel comfortable with instead of people that you are forced to work with (Year 7 student). Finally, the limitation of time for completing the project was noted 'We would like more time if possible. Because three to four days in not really enough time to do that sort of stuff' (Year 7 student).

Analysis of key insights from the festival with reference to the literature

Authenticity and agency

The festival reflected many of the positive attributes of STEAM for building connections between disciplinary concepts such as ethics, design and technologies. Connections were also built between the school and local industry and community through an excursion, guest speaker and a focus on authentic solutions design practices. Utilising a program that had been developed by a Tech School allowed for a strong connection to high growth industries such as housing, sustainability and new energy sectors such as solar power, eco-design and tiny houses as well as community services related to supporting vulnerable groups. Unlike projects run in a Tech School, the prototyping was low-tech with a greater emphasis on the humanities and the arts through the process of defining the problem and prototyping. The lack of scientific and technological integration was seen as a limitation by one teacher

> It was looking to me like an American science fair, where people make models out of glue sticks and things like that and they display them. I originally thought it was like a 'wanna-be' Tech School. Where kids wanted to be in Tech but we didn't have the equipment or the resources or the know how to use any of it, so we use hot glue guns and paddle-pop sticks (Mathematics and science teacher).

This raises the question: What can schools offer for project-based learning compared to what Tech Schools can offer? Potentially secondary schools are a better context for exploring the underlying issues to be solved through deep subject-based learning, while Tech Schools can be utilised for high-tech prototyping as a second iteration of the solutions design process. How both aspects can be aligned is presented in table 3.

Translating a festival into an interdisciplinary unit

The four-day STEAM festival represented a transdisciplinary approach to project-based learning. This allowed for natural links to be explored between key concepts from different subjects under an overarching theme of sustainable and socially aware housing. The use of the design thinking process allowed for a framework to sequence the project through stages which is a contribution to literature on transdisciplinary STEAM design. It also promoted collaboration between students and between teachers from the arts, science, technology and English which reflects the rise of social constructivism in education. Yet, the lack of explicit connections to the curriculum was a missed opportunity for summative assessment of student learning. This was largely due to a lack of time for exploring connections between the design thinking stages and the learning areas from the curriculum. Embedding stages of the design thinking process into subjects would draw on the distinctive expertise of teachers and would address the issue of lack of time

> I found that with our group we have gotten to a stage now where we can start running some tests to see if it works. Once we can run a test to see of it works, then we can get to that next stage. But it has taken us a long time to get there. It has been predominantly building time up until now (Mathematics and science teacher)

The STEAM festival could have increased opportunities for discipline-based learning and teaching by becoming an integrated unit delivered over a term. Yet, an integrated model of STEAM might require a shift in how the school structures learning which according to Thomas and Huffman (2020) can be a source of internal conflict in school leadership. One way that this could happen, is to expand each day of the festival over two weeks and embed parts of the design thinking model into separate subjects. This addresses the issue raised by MacDonald et al. (2019) of a lack of interdisciplinary assessment frameworks, as assessment based on specific descriptors from the curriculum learning areas could be included for each stage of the design thinking process. This would cause minimal disruption to the existing timetable structure used in schools and not require any additional interdisciplinary criteria for assessment. This is summarised in table 2 as a resource for teachers undertaking industry/community-based STEAM projects.

Table 1. STEAM project map with Australian Curriculum embedded in design thinking stages

Project stage	**Science**	**Technologies**	**The Arts**	**Humanities**	**Mathematics**	**Capabilities**
Empathise Week 1		Design and Technologies	Drama Visual Arts	Economics and Business Civics and Citizenship		Personal and Social Capability Ethical and Intercultural Understandings
Define Week 2	Science as a Human Endeavour	Design and Technologies Digital Technologies		Civics and Citizenship	Statistics and Probability	Critical and Creative Thinking Literacy
Ideate Week 3	Science Inquiry Skills	Design and Technologies				Critical and Creative Thinking
Prototype Weeks 4 & 5	Science Inquiry Skills	Design and Technologies Digital technologies	Visual Arts Media Arts		Number and Algebra Measurement and Geometry	Numeracy Critical and Creative Thinking
Test Weeks 6	Science Inquiry Skills	Design and Technologies				Numeracy
Pitch/Present Week 7	Science Inquiry Skills	Design and Technologies	Media Arts Drama Visual Arts	Economics and Business Civics and Citizenship		Literacy Ethical Understanding
Reflect Week 7	Science Inquiry Skills			Economics and Business Civics and Citizenship		Critical and Creative Thinking Personal and Social Capability
Iterate Week 8	Students further develop their prototypes at a local Tech School over 2-3 days using digital technologies such as media production equipment, editing software, AR, VR or advanced manufacturing technologies such as laser cutters, 3D printing, sensors and coding.					

Table 1 is a generic template, designed to suit a wide range of topics. The content descriptors in the Australian Curriculum for *science inquiry skills*; *design and technology processes and production skills*; and *civics and citizenship skills* have stages which align with the design thinking process. Through collaboration, teachers can synthesise key ideas from each of these strands. The STEAM project template also draws on many of the general capabilities. Incorporating cross-curriculum priorities—not shown—would further enhance the project. The table could be fleshed out by a school as a unit plan aligned to the timetable of subjects, with rubrics for assessment and specific year level descriptor codes.

The key insights from the case study will now be generalised as an interdisciplinary unit with reference to design thinking literature and to content descriptors from the Australian Curriculum learning areas, the general capabilities and cross-curriculum priorities. This is undertaken as a demonstration of how integration can authentically address discipline specific curriculum. Specific codes are not provided as they vary across year levels. While the secondary school studied used the Victorian Curriculum, the Australian Curriculum is referenced throughout this paper due to its applicability in schools across Australia. Learning areas and strands from the curriculum are shown in italics.

Elaborating findings for deeper connections to industry and the Australian Curriculum

A valuable starting point for a STEAM unit is to introduce the students to the design thinking process and how enterprising skills and mindsets are key aspects of the future of work. Innovative design in industry relates well to *enterprising behaviours* in *economics and business* from the *humanities and social sciences* learning areas. By examining how enterprising behaviours lead to innovative solutions, students can make the link between their learning and possible future careers.

Week 1: Empathy

Empathetic design requires understanding the user as part of a social and cultural network (Meinel & Koppen, 2015) which can promote *intercultural understanding* from the curriculum. In addition, by drawing on the *personal and social capabilities*, and *civics and citizenship* strand of the humanities, students can explore diversity in people's values and beliefs. Research can be undertaken using *digital technologies* in acquiring data and examining numeric data in *mathematics.* Interviews, surveys, discussion with family members and representatives from industry and the community provide authentic user perspectives to develop a design brief. *The arts* are an ideal platform for empathising with a user by filming interviews in *media arts* and using role-play in *drama.* This helps students to direct their imagination, reasoning and emotions towards understanding who their user is (IDEO, 2011; Hasso Plattner Institute of Design at Stanford).

Week 2: Define

In defining the problem, the goal is to synthesise research about the user to write a succinct problem statement framed by a clear 'point of view' (Hasso Plattner Institute of Design at Stanford, p. 2). Developing deep understanding of the user's problem requires students to use *critical and creative thinking* to succinctly define the 'who', the 'what', and the 'why' of the problem. In *science as a human endeavour*, students can explore the ethical impacts and social opportunities that science and technology create. This directly aligns with *design and technologies* in prioritising between ethical, social, economic and sustainability considerations.

Week 3: Ideate

Ideation is a creative process, which is also social and involves critical thinking (Cababa, 2017). It is ideal for engaging with the *critical and creative thinking capability* as students synthesise a range of researched ideas and possibly derive inspiration from forms in nature. Ideation also links with *design and technologies* as students generate ideas, create plans and investigate suitable technologies and materials to design solutions. They can use graphical and narrative representations of the main ideas, which can be explored in *English, literacy* and *the arts* through stories, songs and visual representations. This can be complemented with the use of *science inquiry skills* to consider what problems can be investigated scientifically. As noted by Luka (2014) the process of empathy, definition and ideation can be repeated to refine the proposed solution, depending on available time.

Weeks 4 and 5: Prototyping

Prototyping is creating a representation of an idea. This can involve rapid prototyping technologies such as 3D printers and laser cutters which are used in Tech Schools or they can be low-tech as in the STEAM festival. Whether high or low-tech, utilising technology requires an understanding of design affordances and constraints which is suited to the *design and technologies* subject. Trial and error, experimentation and purposeful play are processes which are common to the engineer's workshop and the art studio, yet often foreign to schooling (Edwards, 2010). *Science inquiry skills* can formalise the learning process through experiments, field work, simulations and online research to evaluate the feasibility of an idea and its practical limitations. Students can also apply *mathematics* and *numeracy* skills. *Measurement and geometry* can be authentically incorporated as students draw their prototypes in 3 dimensions and from different angles including size and scale. They use *numeracy* to estimate and calculate the amount of materials needed, production time and cost.

Purpose built makerspaces can support prototyping, where students manipulate a range of low and high technologies to socially construct an object of significance (Harel & Papert, 1991). Makerspaces and design studios are excellent environments for bringing together teachers from the arts and STEM subjects to promote innovation (Barker, 2019;

Guyotte et al., 2014). The arts are fundamental to creative prototyping in promoting active, embodied, sensory interactions with materials leading to innovative design and deeper learning. According to Maeda (2017) breaking out of the 'technology loop' of upgrading the same old ideas, requires students to interact with natural materials to promote 'critical thinking—critical making'.

As this was a four-day STEAM project, little time was allocated for testing and presenting student prototypes. The next section elaborates on these aspects of the design thinking process, including curriculum and community links.

Week 6: Test

Testing compares students' prototypes to the user's brief, to establish how well the design solves the problem. The test can involve *science inquiry skills*, as the students collect data to identify patterns and relationships. Surveys or interviews with potential users can be organised in the *English* subject or the *humanities and social sciences*. In a school, it is unlikely that student prototypes will be entirely resolved in terms of presentation and usability. Rather, the prototypes represent the main concepts in a physical form for critical reflection on the concept, to generate feedback according to criteria. In *design and technologies*, the students can create criteria for evaluating the prototype.

At this stage, the broader impacts of the product on society might be considered, by drawing upon *ethical understandings* for discussion about meeting the user's need versus sustainability. This meaningfully links *science, technologies* and *the humanities*. An example question could be 'Where will the resources come from and who will benefit from this solution beyond the user?' According to Donelli (2016) consideration of these questions has sparked a global movement in industry from human-centred design to 'humanity-centred design' to reduce short-term consumer satisfaction at the expense of social and environmental health. This can be related to the *cross-curriculum priorities* in emphasising the importance of consulting local Aboriginal communities, environmental groups and fostering partnerships with countries in Asia for balancing economic and ethical considerations in production.

Week 7: Present or Pitch

The STEAM festival provided an example of informally presenting work to fellow students, teachers and parents. This part of the project could be formalised for deeper connections to curriculum and community.

In this STEAM festival there was no public display of work to local industries or the community which diminished the authentic impact of student work. Displaying student work on a school web page would add authenticity. If students design the web page, valuable skills from *digital technologies* are utilised. The prototypes can be assessed within *media arts* or *visual arts* by evaluating how the presentation of the work communicates the needs and values of the user to a specific audience, as well as the aesthetic appeal of the prototype design.

One way of showcasing student work, is to pitch to the public through a presentation event or in the form of short films. By formally pitching their idea, the students can demonstrate their *science understanding* by using scientific representations and language to communicate key concepts. *Media arts* can play a substantial role if the students produce a pitch video which meaningfully engages an audience using a range of production features. Developing a script and presenting to an audience can also be explored through *drama* and in *English*. *Design and technologies* are central to evaluating the suitability of materials and technologies used, and the social and environmental impact of the solution.

Using a final pitch as a summative piece for assessment can become more authentic by involving local industries and community groups who may act as a panel of judges. Alternatively, feedback on the prototype and pitch can mark the start of a new iterative cycle towards designing improved solutions which better meet the needs of the user. In this way, evaluation of the prototype can also serve as formative assessment to 'plan next steps for individual learning progressions' (Clark, 2012, p. 34).

Week 7: Reflect

Reflection on the design thinking cycle as a learning process, differs to reflecting on the product design. In *science,* reflection for learning involves analysing and evaluating the test data and considering improvements to the inquiry/design process. Ultimately, as MacDonald, Hunter, Wise, and Fraser note it is the learning across STEAM subjects which is the purpose of running a project (2019). While the final product may have failed in meeting the user's brief, students who have taken chances with their design, collaborated as a team, committed to their vision and communicated their ideas well to others are successful learners. To see growth of skills and capabilities as the purpose for learning, is fundamental to life-long learning in any discipline (Lucas, Claxton, & Spencer, 2013).

Reflection is a key aspect of *critical and creative thinking* as students use *metacognition* to review team decisions made and how they could be improved. It is an opportunity for developing *personal and social capabilities* through student evaluation of leadership strategies needed for successfully completing a project. As Dweck's research (2017) has demonstrated, students who can see each experience as a milestone towards greater achievements, develop a 'growth mindset' to embrace the challenges and opportunities of the twenty-first century.

Tech Schools as mediating contexts for extending STEAM learning

The analysis of the STEAM festival presented examples of authentic learning by connecting with industry and community leaders, as well as providing students with agency in choosing topics and autonomy in how they designed their solutions. Yet, the festival format had three limitations: 1) time for students to be immersed in distinct learning processes, 2) connections to curriculum which could be assessed and reported on and 3) a lack of new technologies in designing and prototyping the solutions. Beyond providing school teachers with ready-made programs to run, Tech Schools can play a significant role by supporting secondary schools to run interdisciplinary STEAM projects. Examples include:

- Students undertaking a second design iteration by incorporating Tech School technologies into a more developed prototype. For example, sensor technology could be incorporated into the student models of Tiny-Houses. Sections of the houses could be laser cut as an example of prefabrication. Innovative furniture could be 3D printed. This second stage of construction—moving from low to high-tech materials—through a 3-day design program at a Tech School, could be the culmination of an interdisciplinary term project or incorporated mid-way into the project as a second prototype.
- Tech Schools can provide specific curriculum links and rubrics for assessing STEAM projects. This can support schools to use projects for assessment and reporting.
- Tech Schools can mediate connections between schools and local community groups and industries. This network would provide valuable resources for schools and expertise to establish a STEAM community of practice.

  Table 3 presents the different types of support that Tech Schools as mediating contexts can provide secondary schools throughout a STEAM unit over term.

Table 3: Tech School supports for STEAM units in schools

Design Thinking Stages	Types of Tech School support
Teacher planning & student introduction to the project	Use Tech School templates of design thinking and rubrics that align projects with the Victorian or Australian Curriculum. Tech School contacts industries for school support (guest speakers, excursions, immersion day at Tech School and industry mentors)
Empathise &Define	Tech School may coordinate interviews between students and local industry representatives. Alternatively, pre-recorded interviews exploring issues with a range of relevant industry and community groups can be used.
Ideate, Prototype 1 & Test	Tech School may have useful project management software and resources to help teams collaborate online for ideation. Short prototyping workshops for teachers and students can be run at the Tech School or in the secondary school. Additional resources include online tutorials, help videos, design briefs and examples of high-quality design from industry. Tech School may lend technological resources and equipment for constructing and testing prototypes.
Prototype 2 & Pitch	Utilise the Tech School for three days to produce a more high-tech or refined prototype. Focus student learning on exploring different technologies as well as presenting their prototypes out of the school environment.
Present & Reflect	Tech School can display some high-quality student prototypes on their website. This can be shared with participating industries and community groups. Offer follow-up design programs for interested teams to move the project forward as a real solution.

While Tech Schools are a Victorian initiative, The Australian Industry Group (2017) provides examples of other mediating organisations and institutions which can broker industry partnerships with schools.

Conclusion and outcomes of the study

This paper has presented a case study of secondary school who used the design thinking process in a STEAM festival. Observations and interviews with participating teachers and students provided two key insights:

- The STEAM project was engaging for students through the exploration of a real-world issue (authenticity), working with friends (social learning) and having choice in what and how they learned (agency).

- While some teachers felt that the STEAM festival was authentic to industry it was limited by time and lacked assessable outcomes (curriculum alignment). They felt that a project embedded into subjects over a term could allow for reporting against the curriculum (interdisciplinarity).

The limitation of time and assessment in the festival was addressed in the analysis of the case study to map a generic interdisciplinary STEAM unit over a school term. Specific links to the Australian Curriculum were incorporated and presented in table 2. The role of Tech Schools for supporting schools in Victoria to make the shift from co-curriculum STEAM events like festivals to integrated units was discussed with specific supports outlined in table 3.

Following this research study, the secondary school included in this paper has embarked on the journey of integrating STEAM into the timetable through the design thinking process. This is part of a growing movement to use design thinking to re-structure schooling (Diefenthaler, A., Moorhead, L., Speicher, S., Bear, C., & Cerminaro, D. (2017). Further, in collaboration with the author of this paper, the local Tech School has begun developing rubrics which align projects with the curriculum for year levels 5-10. The shift from STEM to STEAM represents a first step for industry and education towards greater interdisciplinarity. The shift from transdisciplinary STEAM events to interdisciplinary STEAM units in schools represents the next step along the journey of authentic project-based learning for schools.

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Appendix H: Entry in the Encyclopedia of Educational Innovation

Tech Schools, Mediating Contexts for New Pedagogies.

Introduction

Tech Schools are a Victorian State Government initiative to better prepare secondary students for industry changes as a result of technological impacts. Tech Schools serve a political role in promoting student interest in interdisciplinary science, technology, engineering, and mathematics (STEM) careers in high growth industry sectors with potential economic benefits through the development of innovative and marketable technologies. Beyond the vocational focus of Tech Schools through their emphasis on industry, the broad educational potential of Tech Schools to reorientate mainstream schooling to more authentic and engaging student learning is deserving of further research. It is this multilayered mediating role of Tech Schools in connecting school and industry, and their utilization of contemporary pedagogies for student engagement, which is the focus of this entry. The notion of a "mediating context" is utilized to describe the dialectical capacity of Tech Schools to overcome a number of educational antinomies.

A New Context for Secondary Education

Tech Schools are part of an international movement toward helping students develop an entrepreneurial mindset and STEM skills through authentic industry-based projects. Similar secondary schools and educational institutions include the Center for Advanced Professional Studies (CAPS), High Tech High (HTH), and Fairchild Wheeler Interdistrict Multi-Magnet Campus in the USA. Within Australia, the Australian Science and Mathematics School (ASMS) and Pathways into Technology (P-Tech) Network have a similar focus on providing STEM pathways. While Tech Schools in Victoria share many attributes to the schools and initiatives listed, they are not schools. Tech Schools are educational hubs designed to deliver short programs to students visiting from local schools, provide professional development for teachers, build partnerships with industry, and share resources with schools. They provide a facilitating role for schools wanting to engage in authentic project-based learning.

Tech Schools embody distinct pedagogical, physical, and conceptual innovations which have implications for mainstream schools. While each Tech School is a unique response to local employment opportunities, community priorities, and the distinct educational philosophy of its program designers, certain features are common across Tech School facilities. Further, these pedagogical, physical, and conceptual features are distinctively different from traditional school structures.

The Pedagogical Context

Pedagogical innovations in Tech Schools include the development of learning programs through codesign workshops with industry, community, teachers, students, and academics. A design thinking process is used to structure projects, enabling students in groups to solve current industry and community issues. The teaching approach reflects a shift from subject-specific curriculum delivery to a transdisciplinary integration of a range of curriculum content to suit the needs of the project. This is different to other models of integration such as multidisciplinary projects, in that curriculum descriptors are embedded into the project rather than structuring the project to meet subject requirements. Assessment of student learning is primarily focused on the Capabilities from the Victorian Curriculum. Pedagogically, this is a reinstatement of teacher as *learning designer* and *learning activator*. This description of teaching is reminiscent of constructivist theories of learning, most notably John Dewey's progressive vision for education. Yet, Tech School educators also enact distinctively contemporary practices such as collaborative teaching, design thinking, transdisciplinary program design, professional research, and engagement with industry and the community. There is a shift in the practice of educators from specializing in subject-specific content knowledge to utilizing the entirety of the learning context.

Tech School programs encourage students not only to design solutions to set challenges but also to consider possible end goals for their project, allowing for a range of outcomes and methods. While students in teams have opportunities for personalizing projects, they utilize a design thinking process to shape their projects through stages, allowing for a combination of imagination and practical application. Design thinking is a commonly used process in engineering, business, and product/service design. Yet, Tech Schools promote human-centered design which uses empathy for the user as a starting point, to inform subsequent stages of iteration. Through the use of the design thinking process, many Tech Schools have made the transition from STEM to STEAM by incorporating the Arts and the Humanities as the "A." Based on the five-stage Stanford d.school model of design thinking, Tech School projects direct students through seven stages of an iterative design cycle: Empathize, Define, Ideate, Prototype, Test, Pitch, and Reflect.

The design thinking process provides a practical model for integrating the Capabilities from the Victorian Curriculum such as Ethical and Intercultural Capabilities, Creative and Critical Thinking, and Personal and Social Capabilities. Rather than having the Capabilities taught as an independent topic out of context or assumed to be a natural part of learning, the design thinking process allows educators to incorporate the Capabilities in stages to structure student projects. This adds relevance for the Capabilities as learning processes, which can be explicitly taught and assessed in an authentic context. The integration of curriculum into a project through the design thinking process is elaborated later in this entry.

A focus on transferrable skills and "global competencies for deep learning" mark a distinct shift away from content-based teaching to context-based teaching with greater autonomy for educators and students (Fullan et al. 2018, p. 17). While some aspects of the Tech School context are easily identifiable as innovations, such as open and flexible use of space and advanced technology, pedagogical dimensions of context such as student agency, authenticity of learning, roles for teachers and criteria for defining success are harder to define. Research is needed to understand the context, or cultural milieu, of a Tech School. This involves a relational perspective of student–educator dispositions and interactions as well as their relationship with schools and the world outside of school.

The Physical Context

Tech Schools are designed based upon contemporary research on learning environments. Each Tech School is a purpose-built learning environment with flexible spaces which can be reconfigured depending on the needs of different projects. These include maker spaces for low- and high-tech rapid prototyping, presentation areas for lectures and public events, and varied learning spaces for large and small group work. A range of advanced manufacturing technologies are integrated within these spaces, such as laser cutters and 3D printers, digital platforms such as virtual reality (VR), augmented reality (AR), coding and media editing. The purposeful use of high technologies for *creation-beyond-consumption* is empowering for students, particularly students from backgrounds lacking career aspirations in technology.

Tech Schools effectively utilize the physical space by incorporating opportunities for the furniture and equipment to be routinely reconfigured. An "assemblage" of distinct learning spaces differentiates the spatial layout and structures student activities and interactions (Fisher and Dovey 2016, p. 165). These zones promote distinct social and technical interactions between the students, the environment, and technologies. A well-designed zone encourages intuitive usage of tools and furniture by the students to collaboratively complete a task. This is further enhanced by connecting different formal and informal learning zones to the project activities.

Examples of the purposeful design of the environment include informal learning spaces with modular and moveable seating for independent study and small group work involving planning, research, and discussion. Makerspaces, which may be described as formal learning spaces, may include benches that are used for prototyping with low-tech tools. Connected to these settings might be lockable rooms for the use of rapid prototyping technologies such as 3D printers, laser cutters, and CNC routers under teacher supervision. Other formal learning spaces are studios with green screens and media equipment which enable high quality film productions as well as auditoriums with projectors for formal presentations to an audience. These different spaces are used with a clear purpose, yet they are still multifunctional as the furniture is mobile which accommodates the needs of the schools attending and their specific project. Tech Schools are an example of designing physical environments which cue students to distinct activities for increased student engagement and independence.

As suggested by the name "Tech School," technology is a primary feature of the physical learning environment. Yet, understanding how technology supports meaningful learning in Tech Schools requires an evaluation of technology affordances from the perspective of educational theory. From a theoretical perspective, the creative utilization of technology for empowerment is an extension of *constructionism*. Constructionism stems from a common epistemological stance as constructivism in stating that meaningful knowledge is constructed by the learner through active experience rather than transmitted through verbal instruction. More specifically, constructionist theory emphasizes the cognitive development of learners through the use of tools and materials – physical or digital – to construct public objects or meaningful products (Harel and Papert 1991). When this construction is undertaken as a social practice involving discussion, collaboration, and reflection, it can promote higher forms of thinking such as the creative synthesis of ideas and the critical evaluation of a prototype. Tech School learning as a social and contextualized process is also supported by Lave and Wenger's research on situated learning (1991).

Through student immersion in a broad range of rapid prototyping technologies, programmed robots, sensor technology, AR and VR, Tech Schools can either be seen as an embodiment of existing constructionist theory or potentially a driver for the development of new theory. Further research into the capacity for technology to mediate, orientate, and activate learning is needed. This is pertinent to understanding Tech Schools as educational institutions which not only educate *about* technology but educate *through* the use of technology.

The Conceptual Context

Industry is once more changing in response to the potential of technology, placing greater emphasis on developing learner capabilities such as creativity, critical thinking, communication, and collaboration. A narrow and standardized curriculum is now proving inadequate for preparing Australian students for modern employment, where transferrable enterprise skills are increasingly needed.

Conceptually, the Tech School initiative represents a paradigm shift in secondary education. Rather than planning units of work to satisfy curriculum descriptors, Tech School programs begin with authentic industry and community issues for students to solve. Content from a range of subjects is then embedded into these projects, resulting in authentic connections between theoretical understandings and their practical applications in real-world practices. This integration of industry and community into secondary school learning could redress the downward slide in student engagement in science and mathematics through increased agency and authenticity of learning.

Tech School programs cannot be analyzed separate to their context which differs to traditional secondary schooling. Traditional secondary schooling manages learning through compartmentalization, by dividing the curriculum into disciplines with subject content taught in distinct blocks of time. The shift for secondary schools from a learning-management model of education to a learning-growth model is slow due to the inertia created by routine, protocol, and tradition (Fullan et al. 2018). Tech Schools as learning environments are technology rich, the curriculum is STEAM based, and the problems students are exploring have not yet been solved. Further, pedagogical change in relationship to advancing the design of the physical environment is needed to effectively teach in this new context. This will require school educators to upgrade their technical skills in response to new materials and update some of their beliefs regarding pedagogy.

Tech Schools as hubs provide a context for collaboration between industry, community, and schools. In this respect, Tech Schools have a mediating role in fostering relationships between diverse sources of expertise, available resources, and mutually supportive aims. While collaborations between local industry and schools already exist in the form of incursions, excursions, placements, and work experience, the logistical process of organizing these exchanges can be overwhelming and a deterrent both for schools and industries. Tech Schools facilitate the school–industry relationship by utilizing community issues and industry needs as goals for student projects. Through this reverse engineering method to curriculum design, project goals emerge from discussion between industry and community representatives as well as fitting within the Victorian Department of Education and Training industry foci (2019). These goals serve as authentic challenges for students to engage with specific content, knowledge, and skills, as part of the process of solving problems.

The design of problems which promote a transdisciplinary approach to finding solutions is a fundamental characteristic of STEAM education nationally and internationally. Adapting and utilizing content from the standardized curriculum to suit the needs of the project and the interest of the students require a shift in pedagogy. This could challenge some educators who will need support through resources, professional development, and a culture of experimentation and learning. Tech Schools will serve as valuable mediating contexts for enabling first, a change to teacher pedagogy and eventually, a change to the structure of mainstream education.

Summary of Contextual Innovations

Tech Schools provide a multilayered approach to reconceptualizing how secondary education can be delivered. This extends the notion that learning environments must be understood as including the physical, pedagogical and conceptual context of education as well as extending the learning environment to encompass industry and community issues, utilizing authentic manufacturing practices, and integrating curriculum content into projects. This goes beyond merely disrupting traditional education. It represents a revolution in the structure of education. The mediating role of Tech Schools in reconstructing the current dysfunctional education paradigm is analyzed in the following section.

A Mediating Context to Synthesize Educational Antinomies

Tech Schools embody a dialectical relationship between education and community/industry to overcome ingrained antinomies in mainstream secondary education. This has been achieved by constructing Tech Schools as institutions which are neither an extension of schools nor industry. Rather, they are a synthesis of objectives for both contexts resulting in a new type of context: a “mediating context.”

Dialectical tensions underpin the conceptualization of a Tech School as a mediating context. While the Victorian Tech School initiative is a new development, the dialectical method has a rich history which focusses on the study of development through contradictions. Within the field of educational psychology, Lev Vygotsky (1978) considered signs, language, and knowledge as mediating tools/artifacts for humans to indirectly solve complex problems. In this way, human learning is a dialectical process of sociocultural development through the acquisition, creation, and utilization of mediating tools. This built on the dialectical method used by Karl Marx and previously Georg Wilhelm Friedrich Hegel to analyze society and history. Vygotsky’s triangle of mediated action has been elaborated through a field of educational research in cultural-historical activity theory (CHAT). Utilizing Vygotsky’s mediational triangle provides a theoretical framework for understanding the unique context of Tech Schools.

Tech Schools provide a new elaboration of mediated activity at an institutional level as a context for mediating between contradictions including theoretical and practical knowledge; teacher-centered and student-centered pedagogy; and discipline-based and integrated curriculum. The innovative function of Tech Schools as mediating contexts is examined below in relation to each of these antinomies.

Synthesizing Theoretical and Practical Knowledge

The argument that schooling is a disconnected activity to the real-world activity of work is long-standing. Yet, the shift from the "information age," to the age of the "knowledge economy" has bridged the dichotomy between theory and labor in creating technical trades driven by data. The automation of manual labor has transformed the notion of practical work from the application of manual skill to the application of technical knowledge. It is this shift in industry skills which underpins the global STEAM education initiative and creates the purpose for Tech Schools in Victoria.

The argument for schools to better prepare students for this change to work is therefore one of developing students' capacity to apply technical knowledge to analyze data, manage complex sociotechnical-technological systems, and creatively conceptualize improved solutions to real-world issues using a range of social, technical, and technological methods. Traditional schooling is struggling to formulate this objective into learning programs that match with established subject content. Tech Schools have reframed the educational paradigm to directly address the industry skills and capabilities needed. In this way, Tech Schools can mediate the shift for mainstream schools from a contradictory *theoretical learning-or-applied learning* paradigm to a dialectical *applied technical learning* paradigm (Fig. 1). By providing educational programs which are codesigned with community and industry to generate real-world issues for students to solve using technology and design thinking, Tech Schools provide schools with a structure to embed subject-specific knowledge and theory. Not only do Tech Schools foster relationships between industry, community, and secondary schools, they also synthesize applied, social, theoretical, and technological knowledge in educating students for the development of "STEAM-industry-capabilities." This is demonstrated in the diagram below.

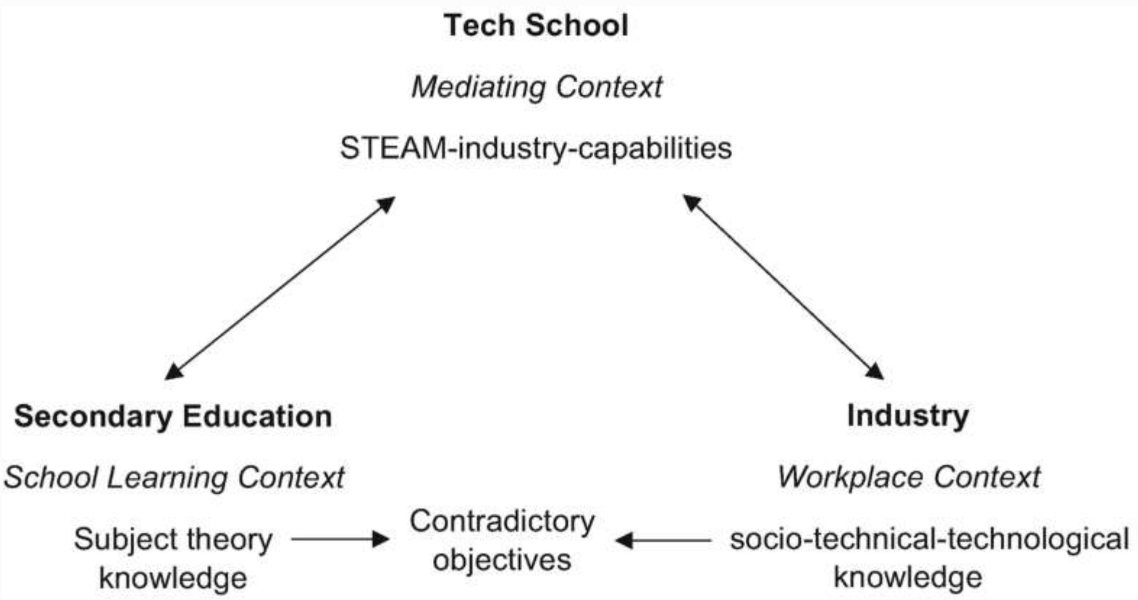

Fig. 1
Tech School program mediates between school theory and industry practice

Synthesizing Teacher-Centered and Student-Centered Pedagogies

Attempts to overcome the dichotomy of teacher-centered and student-centered pedagogies have involved swings between both perspectives resulting in inadequate learning outcomes.

Examples of these extremes include lectures, worksheets, and standardized examinations (teacher-centered) and student selections of topics, open-ended inquiries and self-assessments (student-centered). The argument against the former is the lack of agency and autonomy of learning for the student, and the argument against the latter is the lack of rigor and accountability for the teacher.

Rather than aiming for a midpoint along a scale between both extremes, Tech School programs are a synthesis. By jointly directing the students' and the teachers' focus to a *project objective*, learning and teaching are not divided activities, rather they are mutually supportive perspectives of a common activity: solving a user's problem. The "user" is a member of the community or a client from an industry – usually identified by the students – with a specific need or problem requiring a solution. This dissolves a number of issues regarding the focus of pedagogy and the potential for conflicting roles between students and teachers (Fig. 2).The students' immediate purpose for learning is to solve a user's problem and the teachers' role is to support the students in this endeavor. Through this externally focused activity, both learning and teaching progressively develop through feedback and reflection on the success of the solution in meeting the user's needs and the processes which led to it. Pedagogy thus becomes a synthesized *teaching-for-learning* activity with an objective focus (solving the user's problem). This is demonstrated below.

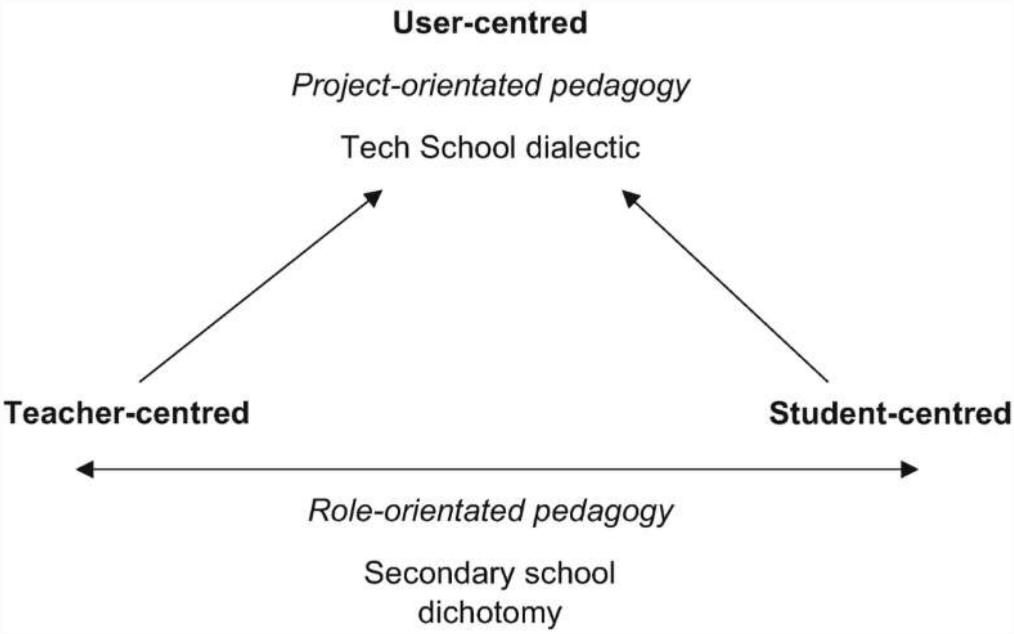

Fig. 2
Project-orientated pedagogy as a dialectic

Connecting Discipline-Based and Integrated Curriculum

The traditional paradigm of secondary school education is subject- or discipline-based. Attempts to build integrated units from separate subjects are complicated by the need for teachers to cover specialized curriculum content. At best, this approach to integration is an additive process, which promotes the exploration of a common theme in each discipline, leading to multifaceted knowledge of a topic. At worst, this approach leads to a patchwork of ideas sutured together, without developing substantial conceptual connections and creating significant additional work for teachers.

Tech Schools operate within a different paradigm which begins with a problem-based project as a structure to support curriculum from different subjects. This can be regarded as a transdisciplinary approach to program development. The advantage is that connections between subjects are already established by the project skeleton which is fleshed-out by content directly relevant to the project. This selective approach to integration has been enabled by a degree of freedom bestowed upon Tech Schools to *enhance* the curriculum rather than *cover* it. This does not mean that schools cannot use Tech School programs to meet curriculum expectations as the process of translation from a transdisciplinary project to an interdisciplinary project is natural to the process of knowledge creation beyond schooling. The Tech School transdisciplinary approach is demonstrated below (Fig. 3).

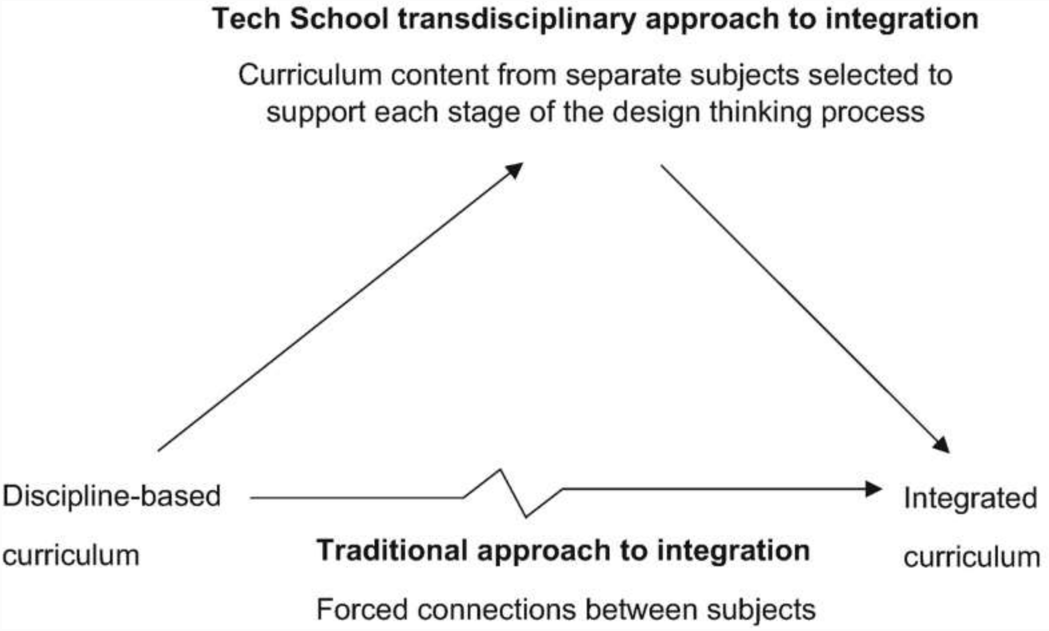

Fig. 3
Tech School transdisciplinary approach to curriculum integration

Conclusion

Tech Schools have been examined as a new context for mediating changes to secondary education. This includes innovations in the pedagogical context, the physical context and the conceptual context. While each of these aspects of the Tech School initiative provide examples of effective contemporary developments in education, it is the capacity of Tech Schools to overcome a number of antinomies which is most innovative. Through the introduction of community and industry issues, a design thinking process and authentic project-based learning, as well as physical design solutions that support the formal and informal activities that occur in the school, Tech Schools can synthesise antinomies such as theoretical and practical knowledge, teacher- and student-centred pedagogies, and discipline and integrated curriculum. Tech Schools as “mediating contexts” embody the dialectical nature of authentic education. This represents a revolution in secondary education, and a provocative challenge for mainstream schools to follow suit.

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