Transdisciplinary STEM Curriculum Enactment:
An Exploratory Case Study in the Queensland Context

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Abstract

Enacting STEM education in Australian schools is an ambitious task, in a climate of unclear definitions and little implementation advice. Should STEM education simply refer to an umbrella term that covers a set of subjects that Australian students need to improve in, or could a cross-disciplinary pedagogy that engages schools in student-led authentic problem-solving be realised? One independent school in Queensland has attempted to enact a transdisciplinary, student-centred ideology of STEM education, through a school developed elective subject that is available to Year 9 and 10 students in the secondary school. The conceptualisation of this subject forms the case, within this descriptive, instrumental case study. The curriculum innovation was born of an emotive response to the heavy weight of responsibility entrusted to STEM teachers in policy.

The methodological approach of this study involves four phases of analysis. Phase One includes a policy analysis conducted via systematic literature search (Xiao & Watson, 2019), content analysis (Denscombe, 2014) and critical policy analysis (Diem, Young, Welton, Cummings Mansfield & Lee, 2014). Phases Two and Three collected data via autoethnographic records and semi-structured interviews, that were analysed using Phronetic Iterative Analysis (Tracey, 2019). Phase Four focuses on methodological triangulation to synthesise the data collected within the previous phases, to distil critical principles of enactment that have the potential to be transferred to other school settings.

Findings of the policy review suggest that the policy-scape of STEM education in Australia experiences tensions between seemingly competing understandings. Many policy documents refer to either a discipline-based umbrella term that encompasses the learning areas of Science, Technology, Engineering and Mathematics or a cross-discipline pedagogies that endeavour to integrate learning areas. It is suggested by this research that broad definitions are employed to allow for a highly variable range of enactment strategies. Findings of the autoethnographical and semi-structured interview data collection suggest that the transdisciplinary enactment strategy employed by the case study school aligns with policy language of cross-discipline STEM and meets other policy descriptions of

STEM education priorities including authentic problem-solving and preparing students for the future of workplaces. Throughout this descriptive, instrumental case study, policy descriptions, pedagogical techniques, curriculum structures and staff characteristics have been explored to extract critical principles of enactment that can be transferred to other school settings. In the process of exploration, a pedagogical framework for enacting a transdisciplinary STEM curriculum innovation was formed.

Conclusions of this research provide a case from which further study could be initiated. Critical principles of enactment identified within the curriculum innovation include explicit teaching and a focus on problem-framing within open-ended problem-solving; a focus on the values, personal characteristics and ways of working of teachers; consideration of the specific roles that a range of staff hold; and descriptions of success. These critical principles of enactment then provide the basis from which schools in other settings could respond to the burden of policy that describes STEM education as an influential factor in the futures of young Australians. This research argues that to authentically actualise polysemy of STEM education definitions in Australian policy, schools could embrace a transdisciplinary pedagogical framework. This, alongside traditional learning areas, can give students the opportunity to meaningfully apply knowledge, skills and 21st century skills to real-world contexts.

Chapter 1: Introduction

1.1 Study Context and Background Information

STEM education has been a topic of prominence in Australia, after focus from Governments and industry intensified in the second decade of the 21st century (Barkatsas, Carr & Cooper, 2019). A diverse range of strategies and approaches to enacting STEM programs in classrooms has been reported in scholarly literature, with a wide variety of viewpoints challenging for superiority. The Australian Chief Scientist's seminal position paper on STEM in Australia (Office of the Chief Scientist [OCS], 2014) highlights five contemporary challenges facing society: "Living in a changing environment; Promoting population health and wellbeing; Managing our food and water assets; Securing Australia's place in a changing world; Lifting productivity and economic growth" (OCS, 2014, p. 5). These are excellent examples of wicked problems, highly resistant to immediate solutions with each requiring the application of 21st Century Skills to resolve (Queensland Curriculum & Assessment Authority [QCAA], 2019). STEM education is positioned as key to developing these attributes in young Australians. Barkatsas et al. (2019) suggest that "a commensurate investment in STEM education [will] ensure a reliable supply of entrants into the future workforce that is well prepared for the predicted growth in STEM-based industries and professions" (p. 1). Further, the Office of the Chief Scientist (2014) states that a "core STEM education for all students encompassing inspirational teaching, inquiry based learning and critical thinking" (p. 20) is presented as a key strategy for developing STEM literate citizens of the future.

Whilst momentum for enacting STEM curriculum in schools continues to build after the release of the suite of STEM in Queensland Schools advice and resources (QCAA, 2017), best practice models for enactment that have been thoroughly evaluated are not, yet, widely available. Fraser, Earle & Fitzallen (2019) reflect that "[d]espite increasing attention being paid to educational reforms in STEM, what actually constitutes STEM remains an issue for scholars, curriculum developers and educators" (p. 11). Hobbs (2019) further reinforces this notion, stating:

> [t]here appears to be enough of a groundswell of interest in all education sectors for STEM to be moving beyond the language of what needs to be

> done to actual practice. …there is no STEM curriculum per se in Australia, and teachers are still working out what STEM can mean for them in their schools. (p. 221)

For an individual teacher or department, charged with STEM enactment in their context, it seems that tangible, concrete and detailed implementation or enactment advice is hard to find. This is because, aside from the QCAA (2017b) STEM in Schools advice, there are few clear or defining policy statements directing the enactment of STEM curricular experiences. Schools, then, must trust in individual teachers' expertise for decisions about design, delivery and evaluation of such programs. Tension between competing agendas of performativity and creativity (Burnard & White, 2008) can mean that reliance on an individual teacher can lead to outsourcing of ideas and dependence on external agencies to provide or sell resources or services to schools. It could be argued that engaging with small, discontinuous tasks using randomly selected, toy-like technology seems to miss the common imperative evident in many STEM education policies and authoritative guidelines, to focus on the need for students to be engaged with problem-solving in real world contexts (Education Council, 2015; OCS, 2014; QCAA, 2017). Classroom implementation and/or enactment of STEM curriculum, then, remains problematic.

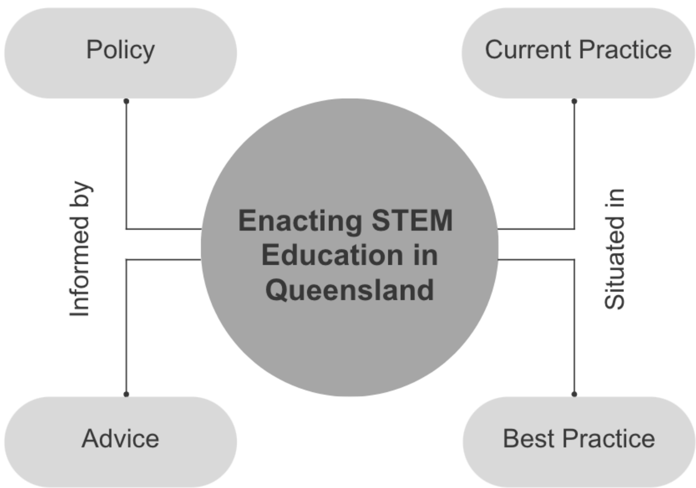

Figure 1. *Enacting STEM education in Queensland*

1.2 Curriculum Implementation and Curriculum Enactment

Fundamentally, curriculum can be regarded as the blueprint for teaching and learning (Brady & Kennedy, 2019, p. 144). Teachers use a curriculum as a basis for program planning, which can be extrapolated down to specific activities that will be enacted with students. However, curriculum is not a static entity and is continually being reviewed, refined and redeveloped to ensure it is up to date with current knowledge and ways of working. In rapidly changing times, many educators — at all levels of schooling — must continually respond to change in their knowledge sets regarding curricula creation and delivery, including emerging pedagogies. Teachers will have to be comfortable with risks, and even thrive when pushing social as well as educational boundaries in order to enact curriculum innovations such as STEM education (Ornstein & Hunkins, 2017). As yet, a published STEM curriculum does not exist in the Australian schooling system, however, curriculum authorities have published a range of resources describing examples of how STEM education could be enacted in schools. For example, QCAA describe why STEM education is important, why schools should invest in STEM education and how STEM education can be incorporated into learning plans in Queensland schools (QCAA, 2017). QCAA provides further advice for designing a STEM unit within one of the key learning areas, such as Science, and gives example unit plans to guide curriculum development (QCAA, 2020; QCAA 2021a; QCAA, 2021b). On a national level, the Australian Curriculum and Assessment Authority [ACARA] provides three publications describing STEM education: the STEM Connections report (2016a), STEM planning and critiquing advice in the form of a planning workbook (2016b), the STEM Report (2016c) with general advice for implementation, and ten illustrations of practice (2015). This suite of resources provides guidance and suggestions but does not mandate a formal learning area to be timetabled in schools. With the growing momentum behind STEM education as a priority for schools to enact, it is plausible that a national STEM curriculum conceptualised as a formal learning area might emerge in the future. Such a development would require teachers to enact emerging pedagogies.

Policy enactment in schools is considered by Ball, Maguire & Braun (2012) to be a process shaped by policy actors, that is “diversely and repeatedly contested and/or subject to different ‘interpretations’ as it is enacted (rather than implemented) in original and creative ways within institutions and classrooms” (p. 2). In this way, the case study examined in this research, herein, looks at curriculum enactment as a “dual process of policy interpretation and translation by a diverse range of policy actors across a wide variety of situations and practices” (Singh, Heimans & Glasswell, 2014, p. 826). In contrast, policy implementation takes a view of policy-as-technology which serves as a strategy for governance by translating specific political rationalities into systems and processes (Beeson & Firth, 1998). When considering effective enactment of STEM education policy— as opposed to the implementation of STEM education policy— then, particular views about the purpose and goals of STEM education become privileged, and the experiences of the people enacting the policy in local settings must be considered and examined. To investigate these views, principles for enactment of new curriculum and in particular, transdisciplinary curriculum, should be established.

1.3 Principles for Effective Enactment of New Curriculum

Ornstein and Hunkins (2017) suggest three general principles that would support effective implementation of a new curriculum: an incrementalism approach, clear communication and support from designers. An “incrementalism” approach suggests that any new curriculum must be carefully considered to ensure it is purposeful and holds meaning, rather than change for the sake of change (Ornstein & Hunkins, 2017, p. 259). After careful consideration about the purpose of the curriculum, effective enactment must be bolstered by clear communication between all stakeholders — from designers to students — but especially on a horizontal plane, between teacher peers. As noted by Ornstein & Hunkins (2017, p. 259), “communication flows more easily among persons who consider themselves equals, and who are equally involved in some curriculum change”. The final principle of support is central to understanding the purpose and intentions of the new curriculum to be enacted. “To facilitate [enactment], curriculum designers must provide the necessary support for their recommended curriculum innovations” (Ornstein & Hunkins, 2017, p. 260). These principles of effective curriculum enactment should be considered when developing new curriculum approaches such as the transdisciplinary pedagogies by STEM education policies, as is the focus of this research project.

1.4 Transdisciplinary Learning and Pedagogies

Curriculum enactment is traditionally controlled by the notion of academic rationalism, this view supports "a preoccupation with prescribed content as "facts" which identify and delineate the academic disciplines" (Forester, 2003, p. 115). For example, generally, in school contexts, it is common practice that Science curriculum is taught in Science classes; Mathematics is taught in Mathematics classrooms. However, Kaufman, Moss & Osborne (2003, p. 2) suggest "…the challenge of never being given enough time to do what we would like to do with our students plagues all educators, but none more so than those who view curriculum as something to be covered". They further suggest that moving beyond the coverage-of-curriculum mentality holds the potential for a step towards meaningful educational reform, stating that "progress demands that we view curriculum development from an entirely fresh perspective, one that moves beyond a compilation of information and skills to be methodically delivered to students" (Kaufman, Moss & Osborne, 2003, p. 2). This shift in mindset presents a significant challenge, given the socio-historical context of many curricula and the way they have traditionally been enacted in the educational system. Costigan (2003) suggests that there are a number of philosophical, cultural and practical boundaries in our educational system that require close examination, and that "crossing these boundaries is an opportunity for an educational conversation that can assist the practice of interdisciplinary teaching and learning" (p. 15). Crossing the boundaries of disciplines, or utilising some kind of "cross-discipline" approach (Costigan, 2003, p. 15), could be considered as a way forward when enacting the emerging STEM curriculum.

'Cross-discipline teaching and learning', is used here as a broad term encompassing a spectrum of pedagogies, which does not have a clear definition in literature but, rather, falls on a continuum of approaches. Helmane & Briska (2017) conducted a theoretical analysis looking for similarities and differences in the etymology of the terms "multidisciplinary", "interdisciplinary", and "transdisciplinary" to create unique definitions for these terms in an educational setting. Figure 2 shows how these terms are being drawn into and used within this research project, herein.

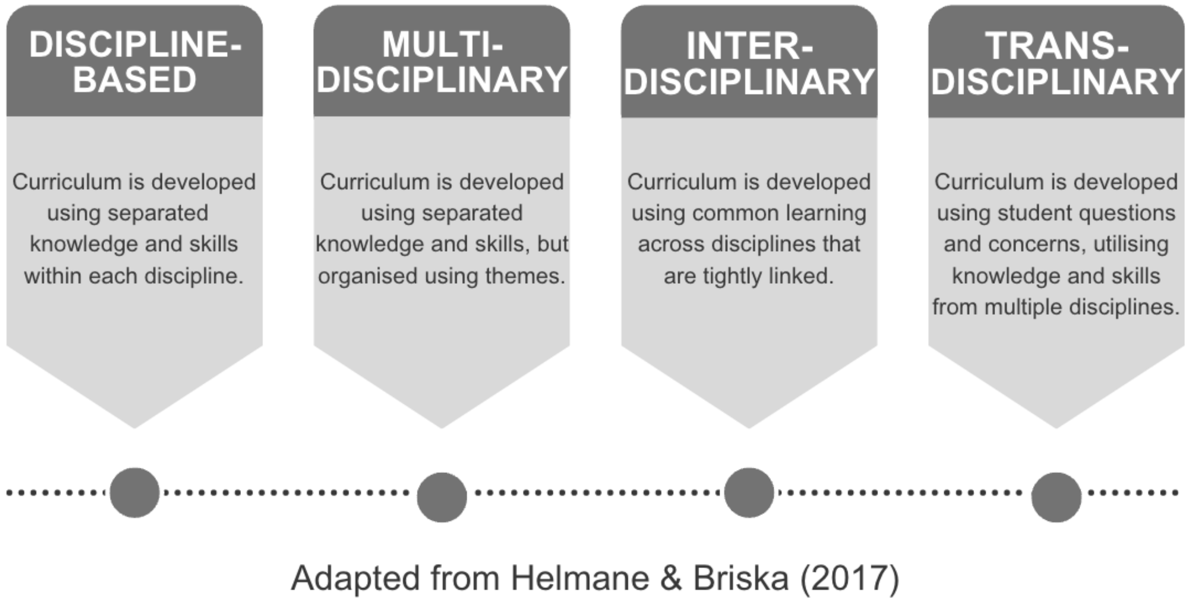

Figure 2. *A continuum of cross-discipline approaches to teaching and learning (adapted from Helmane & Briska, 2017).*

The product of Helmane and Briska's (2017) review suggests that in an interdisciplinary approach, "teachers organise the curriculum around common learning across disciplines" (p. 10). This differentiates from a transdisciplinary approach, where the concepts, research processes and topics converge with significant impact on the perceptions of all sectors involved. Within a transdisciplinary approach, "teachers organise curriculum around student questions and concerns" (Helmane & Briska, 2017, p. 11). This approach appears to align with the priorities of STEM education policy descriptions of problem-solving and questioning. On a definitive level, transdisciplinary learning is characterised as the "exploration of a relevant issue or problem that integrates the perspectives of multiple disciplines in order to connect new knowledge and deeper understanding to real life experiences" (Helmane & Briska, 2017, p. 11). Students experiencing this type of teaching approach are expected to develop key life skills such as teamwork and communication, as they apply interdisciplinary and disciplinary skills in a real-life context. Tasks within this process should be inquiry-based to allow time for discovery, and teachers should organise curriculum using student questions and concerns (Helmane & Briska, 2017; Kaufman, Moss, Osborne, 2003). Helmane and Briska (2017, p. 11) argue that there are only two main routes that lead to transdisciplinary integration: project-based learning and negotiating the curriculum. English and King (2015) further illustrate this point by viewing STEM education as “far more than a convenient integration” (p.3) and suggest STEM education can be viewed a framework that encompasses authentic problem-solving through “cohesive and active teaching and learning approaches” (p. 3).

Helmane and Briska’s (2017) article explores a spectrum of educational approaches from discipline-based to transdisciplinary and plays a central role in the conceptualisation of the curriculum innovation within this case study. The article provides the conceptual basis for the characterisation of transdisciplinary learning used within this research. Helmane and Briska (2017) rely on a synthesis of existing literature to provide definitions of each cross-disciplinary educational approach, with examples of practice, that could easily be translated to classroom environments. This clear highlighting of the distinctions between the range of approaches made it a valuable article within the theoretical conceptualisation of the approach used within this research. However, from a critical realist standpoint, this article lacks robust explanation of the underpinning assumptions and structures of the educational approaches that it reviewed. Whilst the conceptual knowledge outlined is useful for defining terminology within this work, further research could provide a more nuanced understanding of each approach, and transdisciplinarity in particular. Other articles, however, reinforce Helmane & Briska’s (2017) conceptual analysis, specifically within the STEM education context. The American Academy of Arts and Sciences (AAAS, 2013) in Back, Greenhalgh-Spencer and Frias (2015, p. 43) suggest that transdisciplinarity is

> an approach that represents a functional synthesis of methodologies and a broad point of view that combines different fields. This is a step beyond interdisciplinary which borrows techniques from different fields without integrating them to yield new concepts and approaches (p. 2).

Back, Greenhalgh-Spencer and Frias’ (2015) article, describing the application of transdisciplinary theory to STEM education, further suggest that

> the transdisciplinary approach supersedes multi- and interdisciplinary practices and is better suited to addressing complex, open-ended problems because this approach transcends singular or interdisciplinary knowledge and applies domain-specific knowledge within an integrated framework. (p. 43).

A definition of transdisciplinarity within a continuum is further reinforced by Dieleman (2013), who similarly argues for a transcendence beyond interdisciplinary knowledge. Dieleman (2013) suggests that transdisciplinarity is the aspects of problem-solving that are “between, across and beyond” disciplines, and is used to “unite various ways of knowing and to relate us within the world in a more-than-disciplinary way” (p. 68). The conclusions drawn from this comparison of approaches to integrated teaching and learning inform the analysis of the case study school within this research, herein, where focus has been placed on the transdisciplinary end of the continuum of cross-discipline approaches to teaching and learning defined by Helmane and Briska (2017).

1.5 Enacting Transdisciplinary STEM Curriculum

Careful examination of Australian STEM education policy implies that an approach akin to the transdisciplinary approach described by Helmane and Briska (2017) could provide a robust enactment of policy priorities including problem-framing and problem-solving. For instance, English and King (2015), when arguing that disciplines “cannot and should not be taught in isolation” (p. 3) state that “[s]tudies have indicated that students become better problem solvers, display more positive and motivated learning and improve in their mathematics and science” (p. 3). With this in mind, it is important to understand the general guidelines that characterise a transdisciplinary approach with “[m]any curricular activities that combine subject areas or integrate many segments of the curriculum presuppose effective horizontal communication” (Ornstein & Hunkins, 2017, p. 259). However, a key consideration for Australian STEM teachers is that even when developing a transdisciplinary approach, they are developing new pedagogical practices to enact in the classroom drawn directly from policy and authoritative guidelines, rather than a formal learning area, as no such curriculum currently exists. Similarly, clear and actionable enactment advice, specific to a transdisciplinary framework of STEM education, does not currently exist in literature.

Currently, there are many popular approaches to STEM education that include students engaging with skills, tools and technology (ACARA, 2015; ACARA, 2016a; Department of Education and Training [DET], 2016; Education Council, 2019) that cannot be directly categorised as transdisciplinary according to the Helmane and Briska (2017) continuum. Moreover, successful curriculum innovation requires more than a change to the curriculum itself, it also suggests changes to traditional views of education that "...cater[s] to a multilayered student body" (Ornstein & Hunkins, 2017, pp. 266). In addition, Ornstein and Hunkins (2017, p. 262) appeal to curriculum designers to "avoid the do something, anything approach". They make clear that a definite curriculum plan is needed to focus efforts, time and money on sound, rational content and activities. It is argued herein that, currently in the Queensland context, without clear STEM curriculum plans, educators are forced to just do anything in order to appear to be responding with innovation to the STEM education imperative. Ornstein & Hunkins (2017) suggest that whilst many educators would see using the latest technology to signal improvement, it is a "false simplification" (p. 258). Instead, when enacting new curriculum, Ornstein & Hunkins (2017) recommend doing so incrementally and with clear communication and support from curriculum designers.

Moreover, Sahlberg (2015) points to lessons learned in Finland, suggesting some specific guidelines for curriculum change. Firstly, innovations designed to improve student achievement must be technically sound and reflect research findings regarding what does and does not work, not designs that are simply popular. For example, many schools seem to reach out to external agencies involved in selling technology products, such as robotics kits or drones. These external agencies tend to focus on material engagement or engineering concepts, rather than scaffolding the acquisition of critical and creative thinking skills. Vukica, McLeod, Alberts, Tomovic, Popescu, Batts & Sandy (2019) summarise this trend succinctly throughout a review of the way autonomous robots are used to convey "STEM-related concepts in mechanical engineering... electrical engineering… computer science and computer engineering" (p. 1). They suggest that these activities "…are often found in schools in a form of STEM outreach, career days, robotic competitions or during residential on-campus programs” (Vukica, 2019, p. 1). Technology is an important tool in this space, however, can sometimes be seen as the key focus of current STEM enactment strategies. This raises the question, how can the policy imperatives be met, if schools don’t have access to technology? Moreover, how can engaging with technologies be reimagined such that the principles of transdisciplinary STEM Education can be privileged over the act of engaging with the technology itself?

1.6 Case Studies of Enacting Transdisciplinary Curriculum

To build a picture of current STEM enactment strategies in Queensland, a systematic literature search was conducted. This systematic literature review followed the method of Xiao and Watson (2019) and focussed on identifying any cases of transdisciplinary STEM enactment in Queensland secondary schools. Searches used A+ Education, ERIC and JCU OneSearch databases, for the years 2015 to 2020 inclusive. Inclusion criteria included the terms STEM, STEM education, transdisciplinary, Queensland and case studies. Synonyms were also included in the search (see Appendix 1 for a full search term log). Key exclusionary criteria such as location (Queensland or other state), context (Primary or Secondary school) and framework (transdisciplinary or not transdisciplinary) were developed via the screening process, after reading the abstracts of search returns (Xiao & Watson, 2019, p. 94).

The literature search revealed ten Australian case studies, as listed in Table 1, below. No cases were identified that met all the search criteria of Queensland-based, secondary transdisciplinary STEM enactment, however, eight case studies met at least two of these three criteria. Cases were reviewed to establish the description of STEM education privileged in the case, its statement of purpose, as well as identifying key factors that have enabled enactment at each site, for example changes to curriculum and pedagogical structures, or the role of the teacher. In addition, the review sought to identify any barriers to the enactment of the STEM initiative described in each case.

Table 1.

Documented Australian STEM education case studies

Author (Year)	Title	Location	Context	Framework
English (2019)	Learning while designing in a fourth-grade integrated STEM problem	Not stated	Primary School	Not transdisciplinary; integrated, Engineering design process focus
English and King (2015)	STEM learning though engineering design: fourth grade students' investigations in aerospace	Queensland	Primary school	Not transdisciplinary; Engineering design process focus
English and King (2018)	STEM Integration in Sixth Grade: Designing and Constructing Paper Bridges	Not stated	Primary school	transdisciplinary; integrated, Engineering design process focus
English, King & Smeed (2016)	Advancing integrated STEM learning through engineering design: Sixth grade students' design and construction of earthquake resistant buildings	Queensland	Primary School	Not transdisciplinary; integrated, Engineering design process focus
King & English (2016)	Engineering design in the primary school: applying STEM concepts to build an optical instrument	Queensland	Primary school	Not transdisciplinary; integrated, Engineering design process focus
Koul, Fraser and Nastitia (2018)	Transdisciplinary instruction: Enacting and Evaluating a Primary-School STEM Teaching Model	Western Australia	Primary School	Described as transdisciplinary through the use of engineering lessons
McPherson (2015)	Schools as centres of research: a focus on collaboration in action research, in the context of STEM	Queensland	Secondary School	Not transdisciplinary; Cross-faculty collaboration, and interdisciplinary projects;
Summer and Gordon (2019)	Building a flourishing STEM community	Victoria	Primary and Secondary (whole school inclusive)	Not transdisciplinary; Multidisciplinary and Cross-disciplinary

From this search, it can be concluded that there is a significant literature gap of case studies of transdisciplinary approaches (1/8 listed), in Secondary contexts (1/8) in Queensland schools (6/8). Most case studies reviewed were situated in primary school contexts, with one exception (Summer & Gordon, 2019). This study, herein, aims to present an exploratory case study of transdisciplinary STEM being enacted in a secondary classroom in Queensland with a view to contributing to the body of research in the field.

1.6.1 Descriptions of STEM Education Within Case Studies identified through the systematic literature review

Generally, the reviewed case studies describe STEM enactment strategies at the site as integrated or integrative STEM without referring back to broader definitions of curriculum approaches, as defined by Helmane and Briska (2017). For example, authors tend to describe their cases as activities or units that combine teaching and learning across a number of discrete learning areas, such as Maths and Geography (Koul, Fraser & Nastitia, 2018; McPherson, 2015, Summer & Gordon, 2019); or from an engineering-problem based perspective (English, 2019; English & King, 2015; English & King 2017; English & King, 2019; King & English, 2016). Summer and Gordon (2019) describe “whole school STEM and entrepreneurial strategies” that “interweave entrepreneurial thinking into our curriculum” (p. 18). They characterise STEM education as “connections between disciplines” (p. 20), saying “STEM by its very definition is the integration of Science, Technology, Engineering and Mathematics. Where once, schools taught these in isolation, the bridges between are now a key indicator of successful programs” (p. 20). King and English (2016) suggest that “connecting concepts across disciplines is challenging for students who are familiar with learning content in discrete subject areas” and that “research is required to find successful approaches that connect the four disciplines in ways that improve student outcomes”, suggesting that “one way to do this is through engineering experiences housed in real-world contexts” (p. 2763). English and King (2019) report on “one approach to integrating primary school science, mathematics, and engineering, namely, through a set of problem activities in which engineering design served as the “interdisciplinary glue’” (English & King, 2019, p. 864). Koul, Fraser & Nastitia (2018) describe a significant challenge for educators in order to “keep up with the opportunities and demands bought by the information era”, suggesting that “integration of Science, Technology, Engineering and Mathematics into STEM” reflect the transformation. The reviewed case studies generally describe the programs as integrated activities or units that incorporate teaching and learning from two or more learning areas. Within the context of this study, descriptions of integrated, or interdisciplinary STEM enactment strategies are important to consider, as they exist near transdisciplinary enactment strategies according to Helmane and Briska’s (2017) continuum of cross-discipline approaches to teaching and learning (see Figure 2). An interdisciplinary approach suggests that the innovative curriculum is organised around common learning drawn from closely related disciplines (Helmane & Briska, 2017). The key difference to a transdisciplinary approach is that the innovative curriculum is organised around student questions and concerns (Helmane & Briska, 2017). Considering the nuanced distinctions between interdisciplinary and transdisciplinary approaches can shed light on the attributed purpose of STEM enactment strategy within each case.

1.6.2 Purpose of STEM enactment strategy as described by case studies identified through the systematic literature review

Less apparent in the reviewed cases of self-described integrated STEM is the purpose that sits behind the chosen enactment strategy. Beyond a general description of the role of STEM being important for the challenges of the future, many case studies do not explicitly state the purpose of STEM education within the context of the case. For instance, McPherson (2015) states that the purpose was to “introduce the STEM concept and to inspire students to consider STEM as a future career path”. In addition, King & English (2016) suggest that the purpose is “preparing students to be competent in applying and integrating knowledge from a range of sources to solve an engineering design problem is at the core of a successful approach to STEM integration” (p. 2764). English (2019) describes the pedagogical rhythm that most of their studies involve, suggesting that “problem posing and framing, generating ideas and sketching designs, constructing and testing, reflecting on design products and subsequently redesigning can serve as powerful tools in generating important STEM learning” (p. 1029). Koul, Fraser & Nastitia (2018) suggest that “integration of the individual STEM subjects has the potential to prepare students for the workforce of the future by equipping them with 21st century skills such as problem-solving, innovation, creativity, collaboration and critical thinking" (p. 18). Overall, the cases reviewed describe the purpose of STEM education enacted through an integrated strategy, using language aligned with policy wording such as preparing for the future (OCS, 2014) or equipping them with 21st century skills (QCAA, 2019).

1.6.3 Curriculum Structures as Described by Current Case Studies

Generally, curriculum structures can be categorised as discrete tasks, short units or specific skills that are privileged within a whole-school enactment strategy. A range of structures were described across the 8 case studies reviewed. For example, English (2019) describes a longitudinal study where students were tracked from third to sixth grade as they participated in "STEM modelling activities" such as sneaker design (p. 1017). English and King (2015) describe a four-to-five-hour problem-based session, titled the "Aerospace Engineering Challenge" (p. 6) that spanned several class periods with year four students. English, King & Smeed (2017) describe a discrete learning activity that was not summatively assessed, where students tackle an engineering problem activity related to earthquakes in primary schools. King & English (2016) report students were asked to apply "science, mathematics and technology concepts when given an optical engineering problem" in a primary school setting (p. 2764) over two sessions. King & English's (2016) research adopted a conceptual framework "where the design process led to the construction of a physical product" (p. 2765). English and King (2019) describe a three-year study of five sixth-grade classes from two independent schools. "Across the three years, students completed several sets of engineering-based problem activities that drew on their STEM curriculum and required the application of basic engineering design processes" (p. 868). McPherson (2015) describes a three-week unit of work within curriculum time with Year 10 students, with summative assessment of students' collaborative work. Summer & Gordon (2019) describe "K-12 developing the skills and dispositions to pitch a concept; establish a culture of collaboration and creativity; create a framework of design thinking and scale up" (p. 18), but don't provide detail of how this was achieved. Koul, Fraser & Nastitia (2018) provided grade four to seven students with "a series of STEM lessons modified from

Tryengineering to fit local needs" across 10 schools (p. 17). Students were "given a lesson defining engineering and the importance of STEM. In addition, "at least one engineering topic (two to three lessons) was taught in these classes" (Koul, Fraser & Nastitia, 2018, p. 20). In summary, the curriculum structures of the reviewed case studies can be categorised as either discrete activities run by agencies external to the school, or as short interdisciplinary units or the teaching of specific engineering processes.

1.6.4 Pedagogical tools used within case studies identified in the systematic literature review

The pedagogical tools, used to enact STEM based teaching and learning, within case studies varied. Some cases included bringing professionals from a STEM related career into the classroom to act as representatives of industry-based expertise. For example, English and King (2015), English, King and Smeed (2017) and English and King (2019) brought Engineers into the classroom. Teachers and Engineers guided students through the engineering design process, to respond to a contextual problem that had been posed to the students. McPherson (2015) involved "three career scientists, each associated with James Cook University, [who] gave a presentation to the students" (p. 73). In other cases, some pedagogical innovations were described in more detail. For instance, King and English (2016, p. 2765) state "[o]ur engineering activities that contextualise STEM concepts in design-based engineering experiences reflect the theoretical perspectives of situated cognition and sociocultural approaches to teaching and learning", and "[t]he situated cognition perspective suggests that a students' cognition is embedded within, and cannot be separated from, the situation where they engage in meaningful activities in a community of practice" (King & English, 2016, p. 2765). One key pedagogical innovation that was mentioned within the engineering-problem activities was open-ended questioning. "It was explained to teachers that their direct intervention in the students' group work was not desirable. Learning was only facilitated where necessary, such as responding to a student's query by posing a thought-provoking question in return" (English & King, 2015, p. 6). Pedagogical innovations described by each of the case studies include expert guest speakers, engineering-based problem-solving and open-ended questioning techniques.

1.6.5 How the role of teachers is described in case studies identified in the systematic literature review

As described by the Office of the Chief Scientist (2014), teachers play an integral part in the enactment of STEM education, stating "Australia's STEM teachers… must be equipped to deliver course content with confidence and inspiration, and develop all students to their full potential" (p. 21). However, within the reviewed case studies, the role of the teachers was often characterised as playing small parts within an enactment strategy. With King & English's (2016) study, "Teachers in all four classes implemented the activity by following the workbook structure" (p. 2772). English and King (2015) describe the activities teachers were involved in, including "regular briefings and debriefing meetings" as well as being involved in planning and implementing activities. English and King (2019) suggest that "elementary teachers frequently lack the required pedagogical knowledge to effectively implement integrated STEM activities" (p. 865). Further, Koul, Fraser & Nastitia (2018) characterise teachers as "learning facilitators" (p. 26), who play an important role in preparing students to pursue STEM careers. One exception to this characterisation was highlighted by McPherson (2015), who's school had four teachers working collaboratively, "as the focus was the collaborative process between teachers in the three faculties" (p. 73). "All of the teachers who participated in the Project expressed their enthusiasm for collaboration on cross-curricular unit development and recognised the potential of such an association" (McPherson, 2015, p. 74). Some reviewed cases involved researchers entering school environments and providing short activities, rather than teachers delivering them (English & King, 2015; English & King, 2019). Within the reviewed case studies, teachers were generally described as facilitators of activities that were designed by external agencies with only one exception where teachers worked collaboratively to design and enact cross-curricular units.

1.6.6 Barriers and enablers to enactment in each case identified through the systematic literature review

An incrementalism approach (Ornstein & Hunkins, 2017) to enacting STEM education would suggest that barriers and enablers to enactment should be identified to facilitate the necessary curriculum support. Within the 8 cases reviewed, barriers to enactment strategies were identified more frequently than enablers. McPherson (2015) suggests that “the area of assessment gave rise to come conflict” (p. 75), and that “students recognised that people learn and work differently so this impacts on the collaborative process” (p. 75). McPherson (2015) further recognises that “Curriculum, pedagogy and assessment systems are complex, and change in any one system has implications for the other two” (p. 76), implying that barriers may arise due to failing to acknowledge assessment as part of a curriculum framework. English and King (2019) state that a “frequently cited difficulty with an integrated STEM activity is maintaining the integrity of the respective disciplines and ensuring students develop the required learning, especially when multiple content areas are being addressed” (p. 864). English and King (2015) suggest that another barrier to their enactment strategy was the “natural variations in the time teachers devoted to each part of the problem” and suggested that school timetables impacted on the overall outcomes for groups of students (p. 16). Enablers to STEM enactment strategies were clearly presented by Summer & Gordon (2019), who describe particular conditions as “essential in STEM decision making” (p. 18). These included “space, time, budget, resources, mindset, know-how [and] staffing” (p. 18). They further describe enabling conditions within a school environment, stating that “when considering the scope of your environment for STEM innovation, it’s best initially, we found, to move at low tide. Look for situations where it is easy to walk across from one island or active STEM project to another” (p. 19). Barriers to enactment strategies included conflict that arose from assessment, the complex interdependent relationships of curriculum, pedagogy and assessment, maintaining integrity of each learning area within an integrated activity, and the natural variability of teachers when working as facilitators. Enablers to enactment strategies included appropriate space, time, budget, resources, mindset, know-how and staffing (Summer & Gordon, 2019).

1.6.7 Summary

The case studies identified and examined through the systematic literature often described STEM education enactment strategies used in Queensland primary school settings, with one case identified in a secondary school setting (McPherson, 2015) and one whole school approach (Summer & Gordon, 2019). The identified cases usually describe STEM education as integrated activities or units of work that incorporate teaching and learning from two or more learning areas. The purpose of STEM education was found to align with policy descriptions of STEM, such as preparing students for the future, inspiring students or equipping them with 21st century skills. The curriculum and pedagogical design of the reviewed case studies include discrete activities run by agencies external to the school; short interdisciplinary units or the teaching of specific engineering processes; often include expert guest speakers, engineering-based problem-solving; and, open-ended questioning techniques. Teachers were generally described as facilitators of activities designed by external agencies with one exception in which teachers worked collaboratively to design and enact cross-curricular units. Barriers to enactment strategies included assessment strategy conflict, the complex relationships between curriculum, pedagogy and assessment, the integrity of each discipline within an integrated activity, and the natural differences between teachers when working as facilitators of activities. Enablers to enactment strategies included appropriate space, time, budget, resources, mindset, and staffing.

1.7 Knowledge Gaps

STEM education has been positioned as an important part of an Australian education, where students learn to be problem-solvers, critical and creative thinkers in integrated environments (Education Council, 2015; OCS, 2014; QCAA, 2017). However, English and King (2015) identify that the main challenges facing researchers in STEM education is “the lack of a unified and explicit understanding of what [integrated STEM] entails, together with inadequate knowledge of multi-disciplinary content” (p. 3). A review of current case studies of Queensland-based STEM enactments revealed that there is a lack of understanding of STEM education on a definitive level, and that examples of secondary STEM enactment are rare. This research, herein, aims to investigate these silences, with the aim of conceptualising how STEM education can be defined, and how it can be enacted in a Queensland-based secondary school.

1.8 Research Questions

The research investigates how STEM is conceptualised in the Queensland context, and what enactment advice is currently available to teachers in schools. From there, it seeks to investigate and understand the opportunities and challenges associated with enacting transdisciplinary STEM curriculum in a secondary school context, utilising a case study approach of an example at an independent secondary school in Queensland. The overarching research questions that underpin this study are:

1. What are the core constructs of STEM education in Queensland schools, as described by national and state education policy?
2. How is one example of middle-school STEM curriculum conceptualised at one Independent Secondary School in Queensland?
3. What are the critical principles of enactment to enable the case study's STEM curriculum to be transferred to another school setting?

The proposed outcomes of this study are to:

1. Analyse the conceptualisation of STEM curriculum and STEM curriculum enactment advice in Australian and Queensland policy agendas.
2. Explore and describe the process of STEM curriculum enactment at one Independent Queensland school.
3. Provide insights into the enactment of a transdisciplinary STEM curriculum initiative with a view to describing transferrable principles of enactment for STEM curriculum in Queensland.

The methodological approach for addressing these research questions and achieving these outcomes is outlined in the next chapter, Chapter 2.0 Methodology.

2.0 Methodology

This research has been conducted as part of a Master of Philosophy research degree. The project was framed as a descriptive, instrumental case study (Stake, 2005). It sought to describe and explore the enabling and constraining factors associated with enacting a STEM curriculum initiative in one independent secondary school in Queensland. The findings of the case will serve as a foundation from which Helmane and Briska's (2017) theory of transdisciplinary education, Australian and Queensland STEM education policy, and experiences of educators working to enact STEM curriculum in a school setting, can be explored. The findings of this case will describe and evaluate a case of STEM curriculum enactment, which can then be further developed and tested by other secondary and middle school settings located in Queensland, that are also seeking to respond to current STEM education policy imperatives.

This research seeks to answer three questions:

1. What are the core constructs of STEM education in Queensland schools, as described by national and state education policy?
2. How is one example of middle-school STEM curriculum conceptualised at one Independent Secondary School in Queensland?
3. What are the critical principles of enactment to enable the case study's STEM curriculum to be transferred to another school setting?

2.1 Methodological Approach: Descriptive, Instrumental Case Study

This project was framed using a Descriptive, Instrumental Case Study Approach, with a critical realist orientation (Stake, 1995; Stake, 2005). According to Yin (2003), a case study is "an empirical study that investigates a contemporary phenomenon within its real-life context" (p. 9). A case study copes with the technically distinctive situations in which there will be many more variables of interest than data points; relies on multiple sources of evidence, with data needing to converge in a triangulating fashion, and benefits from the prior development of theoretical propositions to guide data collection and analysis (Yin, 2003).

A case study approach has been selected as the primary method for this research project, herein, as it seeks to investigate a bounded system over time (Creswell & Miller, 2000, p. 73) through detailed and in-depth data collection involving multiple sources of information. In addition, case studies are best selected when the research questions are seeking an in-depth understanding about how different cases provide insight into an issue" (Creswell, Hanson, Clark & Moreales, 2007, p. 239). The scope of the research, herein, aligns with Creswell's (2013) view of an instrumental case – in which the case is selected to illuminate a particular set of circumstances. That is, there is a clearly identified case of transdisciplinary STEM curriculum enactment, in alignment with the state's definition of STEM education that creates particular circumstances that will be examined. Furthermore, the defined research questions align with Yin's (2003, p. 6) proposition that "how" and "why" questions are explanatory in nature, making a case study the preferred research strategy.

Taking a critical realist orientation to the use of case study allows researchers to look for causes of known effects via "the study of mechanisms, conditions and capacities as evident in specific cases" (Denzin & Lincoln, 2018, p. 345). Critical realism, as a philosophical framework, seeks to understand and explain the highly complex nature of reality and the causal mechanisms that underpin social phenomena. As suggested by Bhaskar (2008),

> … the world must consist of an ensemble of powers irreducible to but present only in the intentional actions of men; and men must be the causal agents capable of acting self-consciously on the world. They do so in an endeavour to express to themselves in thought the diverse and deeper structures that account in their complex manifold determinations for all the phenomena of our world (p. 9).

Critical realism, selected in an attempt to understand and explain the underpinning mechanisms that drive STEM education in Queensland, often encompasses a broad range of methodological approaches, including policy analysis, interviews, and ethnography, to provide comprehensive and multi-layered understandings of social phenomena.

The research design for the study, herein, focuses on the work of policy as a mechanism that creates particular conditions and capacities for the implementation of STEM curriculum innovations in a Queensland, independent, secondary school.

Methodological triangulation was achieved through the selection of three key methods, in a mixed-method approach. Each method was selected for the purpose of understanding the case from a different perspective, to describe how enactment of STEM education is possible, given a range of underpinning mechanisms. Describing the perspectives of policy, curriculum innovators and teachers of the course of study were crucial to arriving at a set of critical principles of enactment.

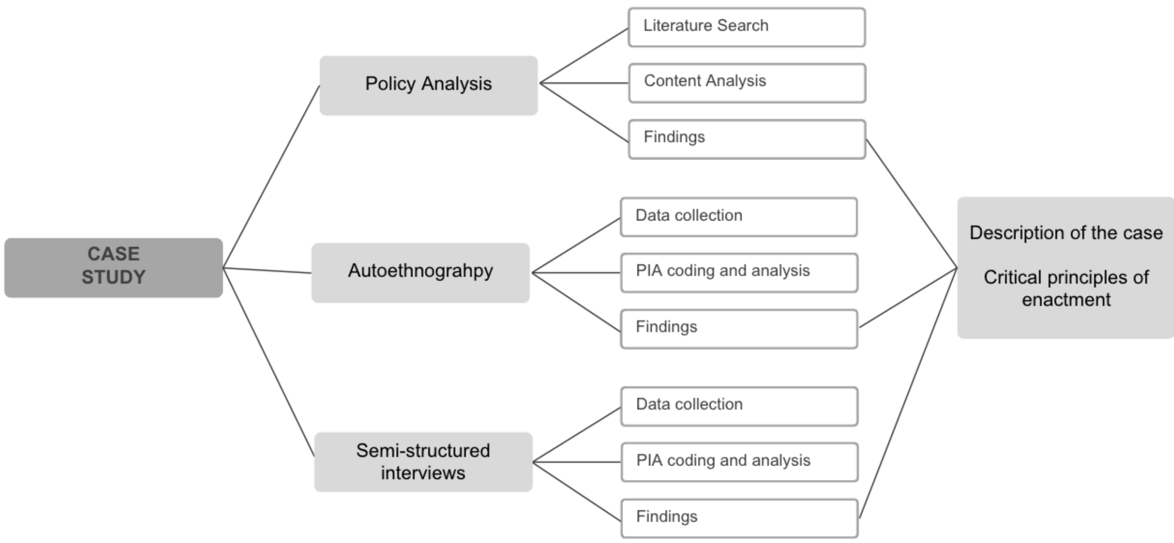

Figure 3. Methods used within the descriptive, instrumental case study to achieve methodological triangulation.

The methodological approach within this descriptive instrumental case study is comprised of four phases of data collection and analysis. According to Creswell (2013), a “hallmark of a good qualitative case study is that it presents an in-depth understanding of the case”, which is accomplished when the researcher “collects many forms of qualitative data, ranging from interviews to observations…” (p. 98). As such, the methodological framework for this project involves phases of investigation with each phase of data collection and analysis further divided into two chronological stages. Figure 4, below, outlines each method of data collection and analysis which culminate in a phase which synthesises triangulated results.

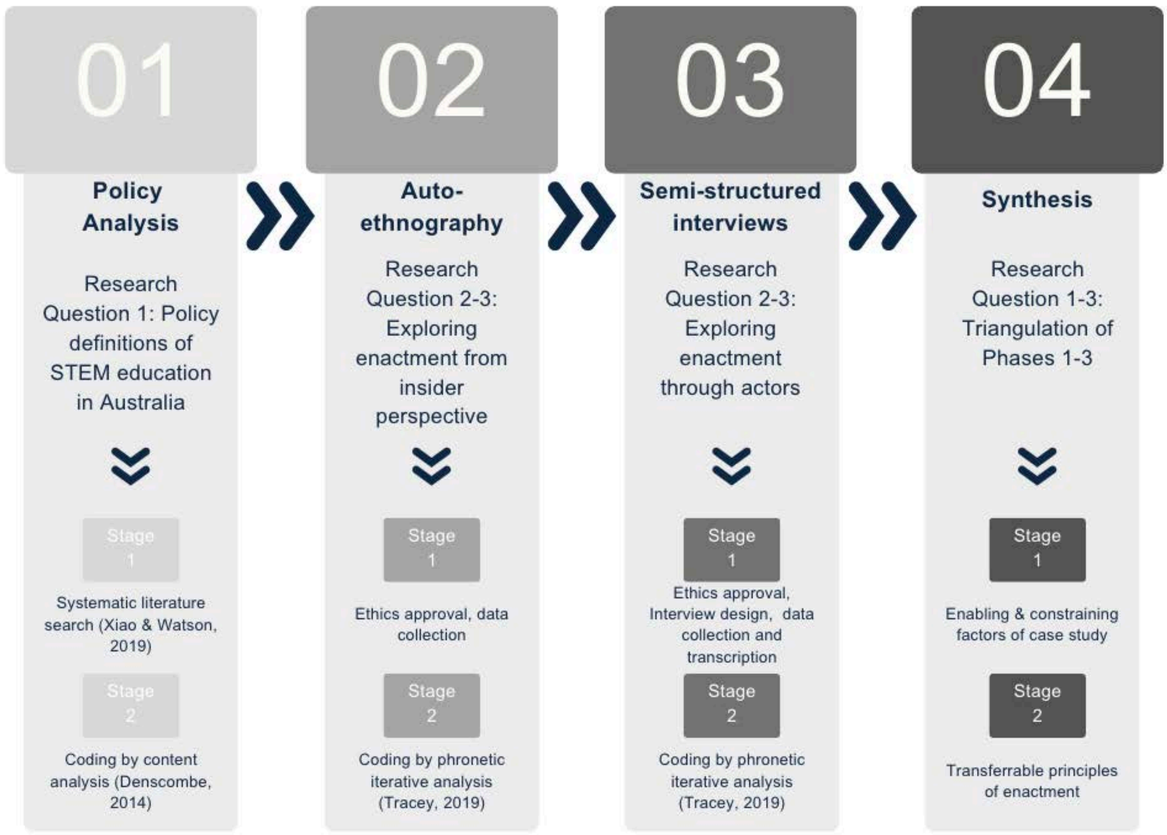

Figure 4. *Analytical phases within the descriptive, instrumental case study*

As can be seen in Figure 2, above, within this descriptive, instrumental case study, data will be collected and analysed throughout Phases 1, 2 and 3 using three methods:

1. Policy analysis – addressing Research Question 1
2. Autoethnography – addressing Research Questions 2 and 3
3. Semi-structured interviews – addressing Research Questions 2 and 3

Methodological triangulation will be achieved through comparison of findings from policy analysis, autoethnography and interview data (see Figure 3). This will enable the researcher to draw conclusions from multiple perspectives to illuminate transferable principles associated with the enactment of transdisciplinary STEM curriculum in a secondary, Queensland context. Each method of data collection and, its associated method of data analysis will be discussed and critiqued, in turn, in the following sections.

2.1.1 Policy Analysis

Research Question One asks, "What are the core constructs of STEM education in Queensland schools, as described by national and state education policy?". To address this question, a policy analysis was conducted, with two stages: (1) a systematic literature search (Xiao & Watson, 2019) and (2) a subsequent content analysis (Denscombe, 2014). Policy analysis was selected to explore the causal, generative mechanisms and contextual understandings of STEM education enactment in Queensland schools.

2.1.1.1 Stage 1: Systematic Literature Search.

A systematic literature search was conducted to identify key policy documents that inform the core constructs of STEM education agendas within Australian and Queensland jurisdictions. Xiao and Watson's (2019) process for a systematic literature search was used:

1. **Selection of appropriate channels for literature search**. According to Xiao and Watson (2019), conducting a comprehensive literature search must involve multiple databases, as no database can contains a complete collection of literature. After searching multiple databases, backward searching was then utilised, to ensure relevant articles that are cited within gathered research were also included, yielding a thorough list of literature (Xiao & Watson, 2019).
2. **Select appropriate keywords used for the search**. Key search terms were derived directly from the research questions, by the breakdown of questions down into concept domains. From there, the concepts domains were extended by the creation and searching of "synonyms, abbreviations, alternative spellings, and related terms", and through the use of Boolean operators (Xiao & Watson, 2019, p. 104).
3. **Screen for inclusion**. After a thorough list of literature was identified, each article was evaluated for suitability, according to inclusion and exclusion criteria such as geographic location and publication year (Xiao &

Watson, 2019). Evaluations were primarily based on review of each article's abstracts, however on occasion the conclusions were also consulted.

4. **Assess quality of results**. After screening for inclusion, full texts of the final list of studies were obtained, for quality assessment. Quality assessment acted as "the final stage in preparing the pool of studies for data extraction and synthesis" (Xiao & Watson, 2019, p. 106). This was completed through the use of a ranking study, that included "ranking the studies based on the same methodological criteria used for inclusion/exclusion" (Xiao & Watson, 2019, p.106).

In accordance with Xiao and Watson's (2019) method, a systematic search for STEM education policy relevant to the Australian and Queensland context was undertaken using A+ Education, ERIC and JCU OneSearch databases, for the years of 2015 to 2020, inclusive. Some policy documents were also identified outside of this time period through backwards searches. The alignment of the research questions to the broad concept domains is demonstrated in Table 2, below.

Table 2.

Broad concept domains (Xiao & Watson, 2019) based on research questions.

Research Question		Concept domain (Xiao & Watson, 2019)
1	What are the core constructs of STEM education in Queensland, as described by national and state education policy?	"DEFINITION"
2	How is one example of middle school STEM curriculum conceptualised at one Independent School in Queensland?	"IMPLEMENTATION"
3	What are the critical principles of enactment to enable this school's implementation strategy of STEM curriculum to be transferred to another school setting?	

Concept domains, which also served as key coding words within the Stage 2 content analysis, were derived from Research Questions 1, 2 and 3, namely; "Definition" and "Implementation". In accordance with step 2 of Xiao and Watsons' (2019) method, further phrases and synonyms were then derived and used within systematic search methods. Synonyms were included in searches using Boolean operators (see Appendix 1 for a full search term log). This systematic literature search aimed to return a suite of contemporary, publicly available, curriculum documents and policy from Federal and State (Queensland) governments, to be analysed with the intention of identifying policy imperatives for STEM education. Inclusion of the concept domain “implementation” rather than “enactment”, as described in Section 2.2, was a deliberate choice following the review of current case studies, as many of the reviewed case studies in STEM education use the term ‘implementation’ rather than ‘enactment’.

2.1.1.2 Stage 2: Content Analysis of Policy Documents.

Stage 2 of the policy analysis involved content analysis (Denscombe, 2014; Elo & Kyngas, 2008) of the recent Australian and Queensland STEM Education policies, frameworks and guidelines identified through the systemic literature search. The aim of the content analysis was to “describe the phenomenon in a conceptual form” by bringing to light the underpinning mechanisms that drive enactment of STEM education in Queensland (Elo & Kyngas, 2008, p. 107). In this instance, the specific phenomenon that is being described is the conceptualisation of STEM education in Australian policy documentation, with a particular focus on how STEM education is defined alongside any implementation advice that is provided. The aim of understanding the policy scape of STEM education in Australia was an important step within the instrumental case study, to gauge whether the case study school’s enactment strategy aligned with policy imperatives. The following method for performing a content analysis are taken from Denscombe (2014):

1. Choose an appropriate sample of texts
2. Break the text down into smaller component units (texts, paragraphs, headlines etc.)
3. Develop relevant categories for analysing the data (key words)
4. Code the units in line with the categories
5. Count the frequency in which these units occur
6. Analyse the text in terms of the frequency of the units and their relationship with other units that occur in the text (pp. 283-4).

The use of Denscombe's (2014) content analysis endeavoured to reveal the values and priorities of policy documents by quantifying the frequency of phrases and synonyms. Once these values and priorities were revealed, a critical policy analysis lens assisted in summarising findings. Critical policy analysis views policy as an outcome of context and power relations, a "…dynamic and complex process" (Ulmer, 2016, p. 1382). Ulmer (2016) further suggests that critical policy analysis "…challenges objectivist assumptions that policy inputs will lead to intended policy outputs" (p. 1382). Through the use of a critical realist lens, the policy analysis endeavoured to understand the mechanisms that underpin the enactment of STEM education in the Queensland context.

Phrases and synonyms listed under the concept domains of "Definition" and "Implementation" concept domains (Xiao & Watson, 2019) were identified through the systematic search strategy and decided upon before beginning the content analysis. In accordance with step 3 of Denscombe's (2014) content analysis method, further phrases and synonyms inductively evolved through the process of breaking down text into smaller units of code. Furthermore, throughout the process of coding the source documents, some phrases occurred frequently that were not directly related to the initial concept domains. The recurring phrases were related to three emergent themes: (1) reasoning behind why STEM education is a high priority for Australia, (2) predicting future trends for the nation, and (3) problematising the very nature of STEM education. Due to the high frequency of occurrence of these three themes, coupled with a direct link to the core constructs of STEM education mentioned in Research Question One regarding the STEM agenda, the concept domain "Why STEM?" was added to the initial list of concept domains stated in Table 2. As such, Table 3, below, lists the final concept domains, phrases and synonyms that emerged through the content analysis. The policy documents reviewed, and the findings of the policy analysis are reported in Chapter 4.

Table 3.

Concept domains, phrases, synonyms and exclusion criteria used in the content analysis of policy documents (Denscombe, 2014; Xiao & Watson, 2019).

Concept domain	Phrases	Synonyms	Exclusion criteria
Definition	Cross-discipline STEM	Integrated, integrative, multidisciplinary, transdisciplinary	N/A
	STEM policy	References to other published policy	Discipline-based students or graduates
	STEM skills	Soft skills, general capabilities, 21st century skills, 4Cs, thinking skills	Discipline-based students or graduates
	STEM students	Qualities of STEM students, qualities of or description of STEM graduates	Discipline-based students or graduates
	STEM teachers	Descriptions of STEM teachers, teacher perspectives, teacher experiences	Discipline-based teachers
	STEM definition	STEM as real-world STEM, or STEM contextually grounded in real-life things and problems	N/A
	Authentic STEM	Describing STEM as real-world STEM, or STEM contextually grounded in real-life things and problems	N/A
	Discipline-based STEM definition	Defining STEM as a suite of discrete disciplines.	N/A
Implementation	STEM curriculum	Work programs, school-based policies, published STEM curriculum	N/A
	STEM education	STEM teaching	Science education, Science teaching, other discipline-based education or teaching
	STEM engagement	Student enrolments, students undertaking a STEM course	Science engagement or enrolments
	STEM implementation	STEM in practice, STEM in schools, STEM advice for schools	Science implementation, or implementing STEM as discipline based
	STEM pedagogy	Ways of working in STEM	Science pedagogy or other discipline-based pedagogy
	Technology-focussed STEM	Coding, drones, robotics, robots	N/A
	Examples of STEM projects (Technology-based)	Real or imagined examples of STEM, that focus on the use of a technology	N/A
	Examples of STEM projects (Problem-based)	Real or imagined examples of STEM, that focus on starting with a problem or problem-based learning	N/A
	Linking STEM to industry	Describing the role industry and business	N/A

		should play in STEM, connecting STEM learning to industry	
Why STEM?	STEM futures	Describing the future of society and the role STEM will play, referencing future work opportunities or higher education pathways	N/A
	Prioritising STEM education	Describing STEM education as important, needed, crucial	N/A
	Problematising STEM	Describing challenges in the STEM agenda, curriculum, pedagogy, or implementation	N/A

An important advantage of using a quantitative content analysis method is that it provided a means of quantifying the contents of a text, and did so by using a strategy that was clear and repeatable by other researchers (Denscombe 2014, p. 284). By assessing the frequency of themes as well as the location of themes within units of text, content analysis revealed the priorities portrayed through the publicly available policy documents. In other words, content analysis revealed:

- What the text establishes as relevant by measuring what is contained (e.g., particular relevant words, ideas)
- The priorities portrayed through text by measuring how frequently it occurs; in what order it occurs" (Denscombe, 2014, p. 284).

The use of content analysis revealed values conveyed in policy related to STEM Education in Australia, by identifying the frequency of value-laden units of text within each policy document. After identifying values through content analysis, the policy analysis then turns to a critical realist policy analysis, as a means for exploring the complexities of the policyscape of STEM education in Australia and qualifying the generative mechanisms that should inform enactment.

Critical policy analysis approaches policy making as a complex and dynamic process, that "challenges objectivist assumptions that policy inputs will lead to policy outputs" (Ulmer, 2016, p. 1382). Policy is not viewed as rational and linear, but rather as contextual and influenced by historical, social and power dynamics (Ulmer, 2016). According to Diem, Young, Welton, Cummings Mansfield & Lee (2014), "[w]hen employed in educational policy studies, critical realist approaches tend to focus around five fundamental concerns" (p. 1072):

1. Attention is given to the difference between policy rhetoric and practiced reality,
2. Attention is given to the roots and development of the policy,
3. Consideration is given to the distribution of power, the creation of “winners” and “losers”,
4. Consideration is given to the broader effect a given policy has on relationships of inequality and privilege,
5. Attention is given to members of non-dominant groups who may resist policy and engage in activism and agency within schools. (Diem et al, 2014).

In addition to these five common focus areas of critical policy analysis, researchers usually seek to “capture the full complexity of policy contexts and the evolution of policy over time” (Diem et al., 2014, p. 1073). This was enacted through significant attention paid to the “complex systems and environments in which policy is made and implemented” (Diem et al., 2014, p. 1073). Through content analysis (Denscombe, 2014) and policy analysis through a critical realist lens focussed on the first two of the fundamental concerns as described by Diem et al. (2014), an understanding of some of the complexities of the policyscape of STEM education in Australia has been presented.

2.1.2 Phases 2 and 3: Phronetic Iterative Approach

Both Phases 2 and 3 used a method developed by Tracey (2019) called Phronetic Iterative Analysis (PIA). For clarity, PIA is explained here, and then referred to in Phases 2 and 3 of the project’s methodology.

Tracey’s (2019) Phronetic Iterative Approach was selected as a method to analyse qualitative data collected from the case study as “phronesis is concerned with contextual knowledge that is aimed toward practical wisdom” (Tracey, 2019, p. 210). With an intention to draw out transferrable principles of enactment (Research Question Three), the anticipated results of phronetic analysis include “use-inspired, practical research that not only builds theory, but also provides guidance on social practice and action” (Tracey, 2019, p. 210). Furthermore, phronetic iterative analysis was selected for use in Phases 2 and 3, as this method encouraged a separation from “sensitizing concepts and research questions”, suggesting it is useful to “set these aside temporarily, and engage with… “open coding””, allowing empirical materials to drive the emic process, rather than predetermined theories (p. 219). This permitted a sterile description of the instrumental case study in Phases 2 and 3, separated from the policy analysis findings, before methodological triangulation in Phase 4. Tracey's (2019) phronetic iterative analysis method involved a number of steps. The application of each step to this project across the phases of the project are outlined below:

1. **Organising and preparing the data:** Tracey (2019) suggests a range of strategies for organising and preparing data, including two key methods employed within this research: chronological organisation and organisation by type of data. Both autoethnographical entries and interview data were organised chronologically, as this "has the benefit of showing the trajectory of your analysis, illustrating how the data were collected and interpreted over time" (Tracey, 2019, p. 212).
2. **Primary and Secondary-cycle coding:** The term code is defined by Saldana (2016, p. 4) to refer to a word or phrase that "symbolically assigns a summative, salient, essence-capturing and/or evocative attribute for a portion of language-based or visual data" (in Tracey, 2019, p. 213). In phronetic iterative analysis, the cycle of coding begins with the generation of a master code list. The master code list should evolve, as "coding typically unfolds in primary and secondary cycles in which the first cycle involves naming a segment of data as a code… and the secondary cycle includes consulting past theories, selecting and synthesi[s]ing the most significant, interesting or frequent codes" (Tracey, 2019, p. 214). Additional codes were added when phrases that were "significant" or frequently occurring became evident through the cycles of coding (Tracey, 2019, p. 214).

In accordance with Tracey (2019), the primary codes were established to examine practical factors that may influence the actions of people in the case working to implement a STEM curriculum innovation. As such, the primary codes are focussed on:

- Specific behaviours, acts or activities in enacting the STEM curriculum: namely, goal-oriented behaviours (e.g., negotiating, blaming, leading),
- Emotion-oriented behaviours, effects of curriculum enactment or constraints (e.g., complaining, compensating, watchful).
- Rules, structures, constraints, ideologies surrounding STEM curriculum enactment at the case study site: namely; timetabling, curriculum, purpose of science curriculum, purpose of science education, purpose of STEM education.
- Character types or roles as individuals in enacting STEM curriculum at the study site: (for example, teachers, curriculum leaders, senior teachers, administration)” (Tracey, 2019, p. 215)

The master list of primary, secondary and tertiary codes derived according to Tracey’s (2019, p. 215) method, are summarised in Table 4. As suggested by Figure 2, autoethnographical data was separated from interview data during primary and secondary cycles of coding.

Table 4.

Master code list: Interview transcript and autoethnography entry coding domains

Primary Coding Domain (Tracey, 2019)	Secondary Coding Domain (Tracey, 2019)	Tertiary Codes
Specific behaviours, acts of activities in implementing the STEM curriculum	Goal oriented behaviours, acts or activities Emotion oriented behaviours, acts or activities	Negotiating Blaming Leading Complaining Compensating Watchful Worrying Conflict
Rules, structures, constraints, ideologies surrounding STEM curriculum implementation at the case study site	Rules Structures Constraints Ideologies	Timetabling and resources Curriculum and pedagogy Purpose of curriculum Purpose of education Purpose of STEM education
Character types or roles as individuals in implementing STEM curriculum at the study site	Character types Roles Assumed character types Assumed roles	Teacher/s Curriculum leader/s Senior teacher/s Administration Students

Throughout each of the data collection methods in Phases 2 and 3, an iterative approach to coding was taken, to ensure a focus on “specific aspects of the data that extend theory or address practical problems, and encourages reflection upon the active interests, current literature, granted priorities and various theories the researcher brings to the data" (Tracey, 2019, p. 209). As such, codes such as 'Worrying' and 'Conflict' emerged. Details on the emergent codes are provided within the findings chapters of both the autoethnographical data (Chapter 5) and the semi-structured interview data (Chapter 6).

3. **Synthesising activities**: Throughout the secondary coding cycle, analytic memos are a useful tool "as part of the analysis process", as they "help researchers figure out the fundamental stories in the data and serve as a key intermediary step between coding and wiring a draft of the analysis" (Tracey, 2019, p. 228). Analytic memos can take many creative written forms and do not have a set structure. Usually, however, they include "one or more of the following features:
    - They define the code as carefully as possible
    - They explicate its properties
    - They provide examples of raw data that illustrate the code.
    - They specify conditions under which it arises, is maintained, and changes.
    - They describe its consequences.
    - They show how it relates to other codes.
    - They develop hypotheses about the code" (Tracey, 2019, p. 228).

Examples of analytic memos are provided within the findings chapters of both the autoethnographical data (Chapter 5) and the semi-structured interview data (Chapter 6). The analytical memos, in their raw data form, are included as Appendix 2.

2.1.3 Autoethnography

Research Questions 2 and 3 refer specifically to understanding enactment of STEM priorities in a contextual case study, asking "How is one example of middle-school STEM curriculum conceptualised at one Independent School in Queensland?" and "What are the critical principles of enactment to enable the case study's STEM curriculum to be transferred to another school setting?". These questions will allow the researcher to characterise the case study's specific enactment strategy, and to draw out transferable principles of enactment. To understand the enactment principles from multiple perspectives, two key methodologies were selected, an autoethnographical study and semi-structured interviews.

Autoethnography is a method that enables the study of a culture or phenomenon of which one is a part, integrated with relational and personal experiences (Adams, Holman Jones & Ellis, 2017). Autoethnography was selected as a methodology within the case study, to allow contextualisation of the case within the broader scope of STEM education as a social phenomenon. The lived experience of the principal researcher provides rich, detailed experiences of the lived reality of designing and enacting a STEM education curriculum innovation within a Queensland schools, that would not have been possible from policy analysis and/or interview data alone. The principal researcher's insights, feelings, attitudes and beliefs associated with the enactment of a STEM curriculum at her school, "at ground level, in the thick of things" (Adams, Holman Jones & Ellis, 2017, p. 50) was documented through this method. Ethically, the use of autoethnography requires recognition that writing about the self means writing about others. Critical realism emphasises the importance of minimising researcher bias and obtaining objective knowledge of social phenomena, in this case the experience of others that is documented in the autoethnographical data. Therefore, the ethical principles of respect for persons, beneficence and justice will be applied in the written representation of the autoethnographical data.

Autoethnographies have a range of methodological advantages including the access to "insider meanings" (Anderson, 2006, p. 389), added vantage points for certain kinds of data and the ability to investigate the connection between biographies and social structures. In this study, the benefits of including an autoethnographical account of the development of the STEM Studies program at the case study site forms the springboard for further study. Without this account and indeed this experience on the part of the researcher, the study overall would not be possible. Inclusion of the teacher researcher's perspective on official enactment advice speaks to a gap in the research identified in the literature review.

Limitations of autoethnographical methods most prominently include the ethical dilemma of retrospective consent (Tolich, 2010) of persons involved in the narrative. "Identifying retrospective informed consent as potentially coercive is foundational for autoethnographers; it creates a natural conflict of interest between an author's publication and the rights of persons mentioned, with the author's interest unfairly favoured over another" (Tolich, 2010, p 60). Therefore, it is the intention of the autoethnography to only include descriptive language of what was observed by the primary researcher, and to only record observations of the reactions of each group as a whole - no individual reactions will be recorded. For example, during the 'Research Phase,' observation of teachers' reactions would be aggregated – i.e., *the verbal responses of the teachers at the case study school indicated that they were largely unaware of a compelling definition of STEM education* – rather than attributing notes to individuals. Furthermore, all the individual persons involved in the autoethnographical account will be invited to share their perspectives through a semi-structured interview. Informed consent will be sought proactively before interviews. This process will be elaborated in section 5.2 of this thesis.

2.1.3.1 Autoethnography Stage 1: Ethics Approval and Entry Production.

Human ethics application was submitted on the 3.6.21, with revisions submitted on the 15.6.21. Approval was granted on the 17.6.21 (approval number H8474, see Appendix 5). Alongside ethics approval, the principal of the case study school has given permission for the school to be named within this research (see Appendix 6). Naming Parklands Christian College [PCC] is an important step within this case study, to distinguish between generalised transferrable principles and specific strategies or decisions that may have been influenced by the demographics or values of the school. Reflecting on Research Question Two, describing the school with identifying features may be important in generating transferrable principles of enactment.

Autoethnography entries were recorded electronically, to ensure they could be date and time stamped. They were compiled into a single document, and identifying information was removed. Identifying information about third parties was aggregated, so that individuals were not identified. For example, autoethnographical data regarding the actions of individual teaching staff was generalised with statements like *conflict arose between teaching staff*. Differentiating between the role of administration and teaching staff was important to ensure the perspectives of these different actors could be compared. Entries were then sorted into chronological order of enactment phases, as mentioned in the body of each entry. According to Tracey (2019), organising materials chronologically “has the benefit of showing the trajectory of your analysis, illustrating how the data were collected and interpreted over time… [and] eases analyses that are interested in correlation and causation” (p. 212).

The STEM curriculum innovation at Parklands Christian College (PCC) was enacted over a series of years from 2017 (Year 1) to 2020 (Year 4), with time spent prior to Year 1 where the project was being planned. Whilst the curriculum innovation is still being enacted in the current calendar year, 2022, the data collection focuses on the period up to 2021. Ethics approval was granted 17.06.2021 and data collection occurred from July 2021, with interviews occurring in October 2021. As such, coding of the autoethnographical data occurred in the following order of enactment phases:

1. Pre-enactment (planning) phase
2. Early enactment phase (Year 1f)
3. Middle enactment phase (Years 2-3, 2018-9)
4. Recent enactment phase (Year 4, 2020)
5. Recent enactment phase (Evaluative focus, 2021)
6. Recent enactment phase (Future focus, 2022)

2.1.3.2 Stage 2: Autoethnography Coding.

Tracey’s (2019) three step methodology of organising data, primary and secondary coding cycles, and synthesising activities was employed to code the autoethnographical data. Data entries were analysed in chronological order, and the coding cycles, as stated in Table 4 were employed.

2.1.4 Semi-structured interviews

2.1.4.1 Semi-structured interviews Stage 1: Ethical considerations and data collection.

Semi-structured interviews were utilised as a data collection method in this study. Interviews provided insight and understandings from people with firsthand experience of the Parklands Christian College STEM Studies subject. These accounts will come from teachers who have been involved in designing and enacting, as well as the leadership team at Parklands Christian College who were responsible for approving the development and subsequent enactment of, the STEM curriculum innovation. A structured, seven stage route (Kvale & Brinkmann, 2009, p. 88) for investigation will be utilised when designing the interview process, which includes thematizing, designing, interviewing, transcribing, interpreting, verifying and reporting. Through this seven-stage, semi-structured design, a standardised set of interview questions can be produced, see Appendix 5 (Fontana & Frey, 2005). The data produced by the interview process can record responses according to the pre-determined coding scheme and minimise non-sampling errors that might stem from respondent behaviours, the method of administration or interviewer questioning techniques (Fontana & Frey, 2005, p. 702).

There are a range of moral and ethical limitations of utilising an interview technique, that often stem from the personal interaction between interviewer and interviewee (Kvale & Brinkmann, 2009, p. 109). These limitations will be counteracted by the methodological triangulation, of relying on several data sources to explore the development and subsequent enactment of Parklands Christian College STEM program. Furthermore, written informed consent was sought proactively and confirmed with each participant before any interviews took place, and a member of the research advisory team was present for all interviews. Semi-structured interviews (Tracey, 2019) were conducted with four staff members at Parklands Christian College. Interviews were scheduled for a maximum of 30-minutes, and at a time and location (in-person, or online via Zoom) convenient to each participant. The interview guide for the semi-structured interviews is included as Appendix 5. The interviews were audio-recorded and then transcribed by Miss Transcription, a confidential, paid service. Participants were invited to review their own interview transcript and to withdraw any data prior to analysis commencing. These data have been stored in accordance with JCU's data storage policies.

2.1.4.2 Semi Structured Interviews Stage 2: Transcription Production and Coding.

Prior to analysis, interview audio recordings were transcribed to ensure accurate coding could occur. Transcriptions were produced by a James Cook University approved third party, Miss Transcription, who provided assurance that the transcription is accurate. Prior to the beginning of analysis, approval was sought from each participant via confirmation of transcript. Each participant was confidentially emailed a copy of their interview transcript and were invited to review it, redacting or altering the transcript to ensure the data that they had given approval for the data to be used in analysis. All four participants returned their transcripts with no changes. Identifying information was then removed and pseudonyms were assigned to each participant, based on their role within the school, for example, one of the Administration staff was assigned was A1. Due to the standardisation of questions within the semi-structured format, the order in which transcripts were reviewed was not important.

Tracey's (2019) three step methodology of organising data, primary and secondary coding cycles, and synthesising activities was employed to code the semi-structured interview data. Data entries were analysed in the same chronological order of enactment phase as autoethnography data, as listed in Section 3.2.3 and the coding cycles, as described in Table 4 were employed.

2.3 Summary

The methodological approach within this descriptive instrumental case study involves four phases of analysis across three . Phase 1 includes a policy analysis, conducted via systematic literature search (Xiao & Watson, 2019) and content analysis (Denscombe, 2014). Phases 2 and 3 include autoethnographical (Adams, Holman Jones & Ellis, 2017) and semi-structured interview data (Kvale & Brinkmann, 2009). Both data sets were approved for collection (human ethics approval number

H8474). Autoethnographical data were collected through analytical memos and semi-structured interview data were collected from four participants. Both the autoethnographical and semi-structured interview data were analysed through Phronetic Iterative Analysis (Tracey, 2019). Finally, Phase 4 of the research project's methodological approach focuses on triangulation and synthesis of data across Phases 1 to 3. The findings of each phase of analysis are detailed in the following chapters:

- Chapter 3: Policy Analysis
- Chapter 4: Overview of the PCC curriculum innovation
- Chapter 5: Phronetic iterative analysis findings: autoethnography and semi-structured interview data.

The final thesis chapter, Chapter 6, provides a synthesis of key findings, discusses limitations of this study and offers recommendations for further research.

3.0 Findings: Policy Analysis

3.1 Background

Differing approaches to enacting STEM programs in classrooms have been reported in Australian Education policy documents over time which present the view that the future STEM workforce is dependent on current students developing problem-solving, critical and creative thinking in real-world contexts where they can authentically and purposefully employ the many technological tools that are available (Education Council, 2015; Department of Education, Skills and Employment [DESE], 2016; DET, 2017; OCS, 2013, 2014). However, almost ten years ago, the Office of the Chief Scientist, when speaking broadly about the STEM agenda, stated "[i]t is not that we lack programs in Australia. There have been many programs, large and small, built over decades. What we do lack is a national approach to STEM" (OCS, 2013, p. 10) and "Australia's STEM investments and policies have suffered from a lack of coordination, misdirected effort, instability and duplication" (OCS, 2014, p. 10). With a magnanimous foundational purpose of STEM education often presented in policy, it could be argued that a national approach to implementation – or best practice model – should follow.

In Queensland, recent policy imperatives have called for urgent STEM implementation in schools; particularly following the release of the suite of STEM in Queensland Schools advice and resources (DET, 2016; QCAA, 2019). However, best practice models for implementation that have been thoroughly evaluated are not, yet, widely available. Moreover, the lack of a definitive STEM syllabus or curriculum documentation to direct the implementation of STEM curricular experiences, results in schools relying on the expertise of individual teachers for decisions about design and enactment of STEM programs. This reliance on the individual teacher has the potential to lead to outsourcing of ideas and dependence on external agencies to provide or sell resources and services to schools.

Anecdotally, STEM resources and services often involve novel technological tools such as robotics kits, drones or coding platforms, or engineering activities (English & King, 2015; English & King, 2019; English, King & Smeed, 2017; King & English, 2016; Koul, Fraser & Nastitia, 2018). It could be argued that engaging with short, discrete tasks with a strong focus on engineering principles or technology without context seems to miss the common imperative evident in many STEM education policies, which call for students to be engaged with authentic problem solving (Education Council, 2015; OCS, 2014, QCAA, 2019). This disconnection between the policy rhetoric and practiced reality highlights a knowledge gap to be explored (Diem et al. (2014). Classroom enactment of STEM from broadly scoped policy documentation seems to have led to many teachers turning first to resources and technology, before deciding on contextual curriculum and pedagogical strategies. Moreover, it is difficult for an individual teacher or department charged with enacting STEM education in their context, to access tangible and detailed advice on the process of STEM policy enactment.

Policy enactment can be considered an imprecise process, which is often shaped by actors. The term ‘enactment’, used within this research, herein, can be distinguished from ‘implemented’. Enactment occurs when interpretations and translations of policy are acted upon in unique and innovative ways that are institutionally contextual (Ball, Maguire & Braun, 2012; Singh, Heimans & Glasswell, 2014). ‘Implementation’, however, is taking a view of policy-as-technology, where specific political rationalities are implemented into systems and processes (Beeson & Firth, 1998). When considering enactment of STEM education policy, interpretations of the purpose and goals of STEM education are privileged and translated according to the context of the actors. As such, a policy analysis has been conducted to review current STEM enactment strategies, with a view to explore a specific case study of transdisciplinary STEM enactment in an independent secondary school in Queensland. Using the case study as a foundation for inquiry, the practicalities of enacting STEM in schools, as informed by contemporary STEM implementation policy, can be explored.

3.2 Systematic Search Results

Using the method detailed in Sections 2.2.1 and 2.2.2, eleven policy documents were returned through the systematic search strategy (Xiao & Watson, 2019), and reviewed via thematic content analysis (Denscombe, 2014) to form conclusions about the landscape of STEM education in Queensland, within the wider context of

Australian STEM education. Two further policy documents that were published before 2015 and referenced in many of the reviewed papers and identified through backward searching, were also identified. These are The Office of the Chief Scientist's two publications, "Science, Technology, Engineering and Mathematics (STEM) in the National Interest: A Strategic Approach" (OCS, 2013) and "Science, Technology, Engineering and Mathematics: Australia's Future" (OCS, 2014). These two additional policies were included in this policy analysis as they are foundational in understanding the current state of the STEM education agenda in Australia, with a specific focus on the Queensland policy landscape. This is relevant to the research, herein, as this case study is located within the state of Queensland. The results of the systematic search are summarised in Table 5, below. The policy documents have been organised chronologically to create a timeline of the modern STEM education agenda influencing Queensland schools in publicly available policy documents. By creating this timeline, attention is then given to the development of the policy over time.

Table 5.

Timeline of modern STEM education agenda in publicly available policy

Year	Author	Document	Source ID
2013	Office of the Chief Scientist [OCS]	Science, Technology, Engineering and Mathematics (STEM) in the National Interest: A Strategic Approach.	1
2014	Office of the Chief Scientist [OCS]	Science, Technology, Engineering and Mathematics: Australia's Future.	2
2015	Australian Centre for Educational Research (Education Council)	National STEM School Education Strategy 2016 - 2026: A comprehensive plan for Science, Technology, Engineering and Mathematics Education in Australia.	3
2016a	Australian Curriculum, Assessment and Reporting Authority [ACARA]	STEM Connections Report	4
2016	Department of Education, Skills and Employment, Australian Government [DESE]	Quality Schools, Quality Outcomes.	5
2016	Australian Centre for Educational Research (Rosicka, C)	Translating STEM education research into practice	9
2017	Department of Education and Training [DET]	Advancing education: An action plan for education in Queensland.	6
2017	Queensland Curriculum and Assessment Authority [QCAA]	STEM in Queensland Schools	7
2017	University of Canberra, STEM Education Research Centre (Lowrie, T., Downes, N. & Leonard, S.)	STEM for all young Australians	8
2019	Department of Education, Skills and Employment [DESE]	Alice Springs (Mparntwe) Declaration	10
2019	Australian Centre for Educational Research (Education Council)	STEM School Education Interventions: Synthesis Report	11

In accordance with the methodology detailed in Section 2.2.1.2 of this thesis, the policy analysis was conducted via quantitative review of key documents identified by the Stage 1 systematic literature search. Denscombe's (2014) content analysis was used to map the core constructs of STEM education in Queensland schools and to identify policy imperatives related to STEM enactment, as described by the Australian and Queensland-based education policies summarised in Table 5. The primary aim here was to describe the policy rhetoric, to be able to compare with the practiced reality outlined in subsequent sections of this study. This was achieved by measuring the frequency of phrases and synonyms within the concept domains (Xiao & Watson, 2019) "Definition" and "Implementation", to reveal the values and priorities embedded in policy. Policy values and priorities were then summarised through a critical policy analysis lens, which “approaches policy making as a dynamic and complex process, [which] challenges objectivist assumptions that policy inputs will lead to policy outputs” (Ulmer, 2016, p. 1382).

3.3 Content Analysis: Results

The content analysis determined the highest and lowest frequently occurring key phrase in each policy document. Nil inclusions of phrases and synonyms were also noted, enabling consideration of which sources could be deemed as relevant to shaping the current policy landscape surrounding the enactment of STEM curriculum in Queensland schools. The results of this content analysis are summarised in Table 6, below.

Table 6.

Frequency of phrases within each source – Highest and lowest frequencies and nil inclusions only

Source	Highest frequency phrase (count of frequency)	Lowest frequency phrase (count of frequency)	Phrases with nil inclusions
1	Cross-discipline STEM (8) STEM teachers (8)	STEM engagement (1) STEM definition (1) Problematising STEM (1)	STEM education, STEM pedagogy, STEM policy, Technology-focussed STEM, Examples of STEM projects (tech-based) Examples of STEM projects (problem-based)
2	STEM futures (12)	STEM pedagogy (1)	STEM curriculum, STEM education, STEM policy, STEM skills, STEM students, Technology-focussed STEM, Examples of STEM projects (tech-based), Examples of STEM projects (problem based), Prioritising STEM education
3	STEM engagement (6)	STEM education (1) STEM policy (1) Authentic STEM (1) Technology-focussed STEM Prioritising STEM education (1)	Cross-discipline STEM, STEM pedagogy, STEM students, Examples of STEM projects (tech-based), Examples of STEM projects (problem based), Problematising STEM
4	STEM futures (3)	STEM engagement (1) STEM policy (1) Authentic STEM (1) Technology-focussed STEM (1) Prioritising STEM education (1)	Cross-discipline STEM, STEM curriculum, STEM education, STEM implementation, STEM pedagogy, STEM skills, STEM students, STEM teachers, STEM definition, Examples of STEM projects (tech-based), Examples of STEM projects (problem based), Linking STEM to industry, Problematising STEM

5	Cross-discipline STEM (9)	Examples of STEM projects (problem-based) (1) Examples of STEM projects (tech-based) (1) STEM futures (1)	STEM pedagogy, STEM policy, Technology-focussed STEM, Prioritising STEM education, Linking STEM to industry, Problematising STEM
6	Linking STEM to industry (5)	STEM engagement (1)	Cross-discipline STEM, STEM curriculum, STEM education, STEM implementation, STEM pedagogy, STEM policy, STEM students, STEM definition, Technology-focussed STEM, Examples of STEM projects (problem based), Prioritising STEM education, Problematising STEM
7	Discipline-based STEM definition (7)	STEM curriculum (1) STEM implementation (1) STEM policy (1)	STEM education, STEM pedagogy, STEM students, STEM definition, Technology-focussed STEM, Examples of STEM projects (tech-based), Examples of STEM projects (problem based), Prioritising STEM education, Problematising STEM
8	STEM skills (8)	STEM students (1) STEM teachers (1) Examples of STEM projects (problem-based) (1) Prioritising STEM education (1) Problematising STEM (1)	STEM education, STEM engagement, Technology-focussed STEM, Examples of STEM projects (tech-based)
9	STEM definition (8)	Technology-focussed STEM STEM futures (1) Prioritising STEM education (1)	STEM education, Examples of STEM projects (tech-based), Examples of STEM projects (problem based), Problematising STEM, Linking STEM to industry, Problematising STEM
10	Authentic STEM (1) Discipline-based STEM definition (1) Technology-focussed STEM (1) Prioritising STEM education (1)	Authentic STEM (1) Discipline-based STEM definition (1) Technology-focussed STEM (1) Prioritising STEM education (1)	Cross-discipline STEM, STEM curriculum, STEM education, STEM engagement, STEM implementation, STEM pedagogy, STEM policy, STEM skills, STEM students, STEM teachers, STEM definition, Examples of STEM projects (tech-based), Examples of STEM projects (problem based), Problematising STEM, STEM futures, Linking STEM to industry, Problematising STEM
11	Examples of STEM projects (problem-based) (5)	STEM engagement (1) STEM pedagogy (1) STEM policy (1) STEM students (1) STEM teachers (1) STEM definition (1)	Cross-discipline STEM, STEM curriculum, STEM education, STEM skills, Authentic STEM, Technology-focussed STEM, Examples of STEM projects (tech-based), Problematising STEM, STEM futures, Prioritising STEM education, Linking STEM to industry, Problematising STEM
ALL	Discipline-based STEM definition (47)	STEM education (4) Technology-focussed STEM (4) Examples of STEM projects (tech-based) (4)	

3.3.1 Findings: Quantitative Content Analysis

Table 6 shows the highest and lowest frequency of phrases identified throughout each of the policy documents, including phrases which did not appear within each source. Analysis of the data presented in Table 6, revealed the following findings:

- The two highest frequency phrases in single sources are “STEM futures” (12 occurrences in Source 2) and “Cross-discipline STEM” (9 occurrences in Source 5).
- The highest occurring phrase in any single source was “STEM futures”, with 12 appearances in Source 1.
- The highest occurring phrase across all sources (1-11) was “Discipline-based STEM”, with 47 appearances in total.
- “Discipline-based STEM definition” appears in all sources.
- Source 8 contained the most diverse range of phrases, with the least number of phrases with nil appearances (4).
- “Cross-discipline STEM”, “Discipline-based STEM” and “STEM futures” were the only phrases with more than one source listing them as the most frequently occurring. E.g., “STEM futures” was the most frequently occurring phrase in Source 1 and Source 5.
- All other phrases apart from “Cross-Discipline STEM”, “Discipline-based STEM” and “STEM futures” only appeared in the most frequent list once.

According to Denscombe (2014), the primary goal of thematic content analysis is to reveal “[t]he priorities portrayed through text by measuring how frequently it occurs; in what order it occurs” (p. 284). Table 7 shows the total occurrences of phrases across all reviewed sources, ranked in order of the highest frequency to the lowest, including the percentage of total representation that each phrase had across the assemblage of eleven policies under analysis.

Table 7.

Total occurrences of phrases and synonyms across Sources 1 to 11, ranked in order of highest to lowest frequency of phrase or synonym.

Phrase or synonym	Total Occurrences	Concept domain	Percentage of all occurrences
Discipline-based STEM definition	47	Definition	12.14%
STEM futures	35	Why STEM?	9.04%
Cross-discipline STEM	33	Definition	8.53%
STEM skills	32	Definition	8.27%
STEM teachers	29	Definition	7.49%
Authentic STEM	26	Definition	6.72%
STEM engagement	24	Implementation	6.20%
STEM curriculum	23	Implementation	5.94%
STEM definition	23	Definition	5.94%
STEM implementation	21	Implementation	5.43%
Linking STEM to industry	19	Implementation	4.91%
STEM students	16	Definition	4.13%
STEM policy	12	Definition	3.10%
STEM pedagogy	11	Implementation	2.84%
Examples of STEM projects (problem-based)	10	Implementation	2.58%
Prioritising STEM education	8	Implementation	2.07%
Problematising STEM	5	Why STEM?	1.29%
STEM education	5	Implementation	1.29%
Technology-focussed STEM	4	Implementation	1.03%
Examples of STEM projects (tech-based)	4	Implementation	1.03%
TOTAL OCCURRENCES:	387		

Table 7, above, shows the total occurrences of phrases and synonyms across all eleven sources, ranked from most frequently occurring to least frequently occurring. However, to extrapolate generalised foci of policy documentation, the associated concept domains of each phrase are listed in Table 8, below.

Table 8.

Total occurrences of phrases and synonyms per concept domain

Concept domain	Total occurrences	Percentage of occurrences
Definition	218	56.33%
Implementation	129	33.33%
Why STEM?	40	10.34%
TOTAL:	387	

3.3.2 Summary of key findings of quantitative content analysis

Reviewing the frequency and ranking data of phrases and synonyms presented in both Tables 7 and 8, showed:

- “Discipline-based STEM definition” is the highest frequency phrase, with a total of 47 occurrences across the 11 sources (Table 7).
- “STEM education”, “Technology-focussed STEM” and “Examples of STEM projects (tech-based)” are equal lowest frequency phrases, with a total of 4 occurrences across the 11 sources (Table 7).
- The “Definition” concept domain is the highest frequency category with 218 occurrences, with 56.3% of key phrases falling into this category (Table 8).
- The “Implementation” concept domain first appears at 8th position on the ladder of frequencies. Key phrases from this category occur 129 times, or 33.3% of all occurrences (Table 8).
- “Why STEM” concept domain has the lowest frequency within the policy assemblage (Table 8), however one synonym from this category —, “STEM futures” — has the second highest frequency of total occurrences for an individual key phrase, with 35 occurrences begin recorded (Table 7).

Taken together, the results of the quantitative content analysis show that work to develop and define STEM is of significance in all policy documents. Synonyms of the concept domain ‘Definition’ are present in 56.33% of all phrase occurrences. Each of the reviewed policy documents attempt to define STEM or refer to how STEM will be characterised within the publication. Some publications describe STEM education as a suite of individual disciplines. For example, “STEM education is a term used to refer collectively to the teaching of the disciplines within its umbrella –

science, technology, engineering and mathematics” (Education Council, 2015, p.5). However, when looking at the total occurrences across all eleven sources, the phrase of “Cross-discipline STEM” is the next frequently occurring phrase within the “Definition” concept domain. Even within single documents, the definition of STEM education can seem disjointed. For example, DESE (2020b) describes STEM education as an umbrella covering disciplines and also “…a cross disciplinary approach to teaching that increases student interest in STEM related fields and improves students’ problem solving and critical analysis skills” (p. 5). These data show a lack of clear definition of STEM or STEM education that is presented uniformly across the policy documents reviewed, a notion represented in literature as the “STEM identity crisis” (Barkatsas, Carr & Cooper, 2019, p. 2). Fraser, Earle & Fitzallen (2019) describe this identity crisis, saying “[t]he multi-faceted nature of the definition provides little guidance for teachers, which makes it unlikely it will influence educational policies, programs and practices” (p. 12). Whilst all sources include reference to a discipline-based understanding of what STEM is, many also reference cross-disciplinary approaches (ACARA, 2016a; Education Council, 2018; Lowrie, Downes & Leonard, 2017; OCS, 2013, 2014, QCAA, 2019).

Reflecting the spectrum of STEM education as both discipline-based subjects and cross-discipline experiences, examples of cross-discipline STEM education may be more likely to be found as clubs or extracurricular activities that focus on technology (Chaiwongsa, Kinboon & Yanasarn, 2019; VanMeter-Adams, Frankenfeld, Bases, Espina & Liotta, 2015). Fraser, Earle and Fitzallen (2019) poignantly suggest that “[i]n recent years, some Australian teachers/schools have enacted STEM pedagogies, in the face of a curriculum that remains focussed on the siloed, traditional disciplines of science and mathematics, and more recently digital technologies… but a more consistent and equitable approach is needed” (p. 9). This suggestion supports the findings of the policy analysis herein. For instance, when the occurrences of ‘discipline-based STEM’ (the highest-ranking phrase or synonym with 12.14% of all occurrences) and ‘cross-discipline STEM’ (the third highest ranking phrase or synonym with 8.53% of all occurrences), a tension arises between cross-discipline view of STEM education and one of STEM as discipline-based learning. These variations in the definition of STEM education demonstrate that the is a diverse range of policy perspectives about what it might mean to implement or enact STEM education. This finding aligns with the view of Lowrie, Downes and Leonard (2017) who postulate that “[c]urrent approaches to STEM education are diverse, and teachers are faced with many challenges in implementing programs” (2017, p. 41).

“STEM futures”, including synonyms (see Table 5) was the second highest occurring phrase across all sources. The high frequency of occurrence of this phrase, coupled with the sentiment of the phrase in trusting the STEM agenda to meet the needs of Australia’s future, “STEM futures” provides the foundation for STEM being included in education in Australian schools. The notion of ‘STEM futures’ provides a clear driver behind why STEM has become a focus for educational institutions as well as the wider society, with strongly emotive sentiments such as “[t]he reality is we can’t relax. We can’t be complacent. There can be no sense of entitlement. We must understand that we will get the future we earn” (OCS, 2013, p. 3). The Office of the Chief Scientist’s papers focus on STEM being the pathway to “A Better Australia’, stating it is the “primary purpose of STEM in Australia – the reason for doing things” (2013, p. 4). There are many references to the careers and workplaces of the future, predicting the requirements of ways of working including "[d]eep knowledge of subject, creativity, problem-solving, critical thinking and communication skills - are relevant to an increasingly wide range of occupations. They will be part of the foundation of adaptive and nimble workplaces of the future" (OCS, 2014, p.7). It seems that the purpose of STEM education is encapsulated in visions of an improved Australian society of the future (OCS, 2014). However, without a clear and definitive shared understanding of what STEM education is across the educational sector, the “core STEM education for all students” (OCS, 2014, p. 20) has the potential to be interpreted differently by each teacher charged with enacting “inspirational teaching” (OCS, 2014, p. 20).

The most frequently occurring phrase across all policy documents — with 12.14% of all occurrences — is “Discipline-based STEM definition”. This phrase falls within the “Definition” concept domain, suggesting that the most common understanding of STEM is an umbrella term, referencing a suite of separate subjects including Science, Technology, Engineering and Mathematics. Across all policy documents, however, “Technology focussed STEM” and “Examples of STEM projects (tech-based)” were the equal lowest frequently occurring phrases. This tension between the rhetorical importance of ‘STEM Futures’ alongside the paucity of enactment strategies presents an interesting contrast. Policy language suggests that defining STEM is of crucial importance to Australia’s future, however, implementation and/or enactment advice that may be expected, such as technology-based conceptualisations of STEM education, rarely exist in policy. Phrases and synonyms related to “Technology-focussed STEM” and “Examples of STEM projects (tech-based)” were ranked lowest of all occurrences in 19^{th} and 20^{th} place, with only 1.03% of all occurrences each. Rather, “STEM Skills” ranked fourth, with 8.27% of all occurrences. Fraser, Earle and Fitzallen (2019) suggest that STEM skills such as research, logical thinking and quantitative analysis alongside qualities of creativity, open-mindedness, independence and objectivity are found in integrated and engaging STEM teaching and learning, but that “this has been hampered by an insufficient collective understanding” of STEM education (p. 10). However, Fraser et al. (2019) suggest that STEM capabilities, epitomised in the General Capabilities dimension of the Australian Curriculum, “remain peripheral to teacher practice”, despite being “desirable and consistent with an integrative approach to STEM education” (Fraser, Earle, Fitzallen, 2019, p. 13). A lack of clear and specific definition and enactment advice may suggest that cross-discipline STEM education has been driven to the margins of practice, where the implications of teaching, learning and assessment are free from formal curriculum requirements, and where the intent and purpose of STEM education is open to interpretation.

3.4 Discussion: Findings of Quantitative Content Analysis of Policy Documents

The coding and analysis of policy documents has endeavoured to outline the landscape of STEM education policy in Australia, with a focus on the reasoning for, and definition of, STEM and STEM implementation advice for schools in Queensland. The frequent use of phrases and synonyms such as “STEM futures” demonstrate the significance assigned to the STEM Education agenda to meet the needs of Australia’s future and provide the rationale for STEM being included in education in Australian schools. Despite defining STEM as a policy imperative, the policy analysis conducted, herein, suggests that there is no clearly agreed definition of STEM, nor is a definition used consistently across the policy documents reviewed. Moreover, competing views of ‘discipline-based STEM’ and ‘cross-discipline STEM’ are evident. Fraser, Earle and Fitzallen (2019) strongly argue that these competitive views are hampering the efforts of STEM education to meet its overarching purpose, stating “[w]hile socially responsible STEM education, focussed on preparing students for 21st century problems and goals, requires the development of higher order capabilities, the structure of the Australian Curriculum… and the adherence to traditional approaches… act as impediments. The structure of the Australian Curriculum… consisting of separate subjects and strands within them, limits an integrated approach to STEM learning and teaching” (p. 13). Implementation advice is not clear in policy documentation, and the absence of phrases related to technology-focussed STEM and examples of practice that are tech-based was notable. Also absent were references to a STEM curriculum, despite indications from the Office of the Chief Scientist that “becoming A Better Australia starts with education” (2013, p.13). suggesting that it is the actions and decisions of individuals within schools that realise these policy objectives, rather than through formal, curriculum-based directions from education systems. Through the systematic review of the policy assemblage relevant to Queensland, Australia, two core constructs of STEM education have emerged: defining what the term “STEM education” means, and the provision of advice for implementation of STEM Education.

Implementation advice and the success criteria for a quality STEM program is highly varied between publications, based on the definition of STEM adopted by the author. For example, the National STEM school education strategy 2016 – 2026 details five areas for national action, the first being “increasing student STEM ability, engagement, participation and aspiration” (Education Council, 2015, p. 6), whereas the Alice Springs (Mparntwe) Education Declaration states “the STEM learning areas are a key national focus for school education in Australia and are critical to equip students to engage productively in a world of rapidly changing technology” (Department of Education, Skills and Employment [DESE], 2019, p. 15). As a generalisation, the focus for action seems to be activities that either lift student engagement or improve student achievement (ACARA, 2016a; DESE, 2019;

Education Council, 2015). A spectrum of models is then presented, which can range from outside of school activities and excursions to curriculum time dedicated to teaching of integrated STEM. In summary, the content analysis findings highlight two key issues related to the work of teachers and schools when implementing and/or enacting STEM education: (1) a lack of definitional clarity of STEM education; and (2) a lack of formal curriculum-based STEM education implementation advice. The implications of these findings will now each be examined through a critical policy analysis of the eleven key policies examined in the content analysis.

3.5 Critical discourse analysis of STEM education policy documents

Critical approaches to policy research are becoming increasingly more common within educational research, as they facilitate the exploration of policy in all their complexities (Diem et al., 2014). As detailed in the methodology outlined in Chapter 3, critical discourse analysis facilitates the exploration of

> policy roots and processes; how policies are presented as reality are often political rhetoric; how knowledge, power, and resources are distributed inequitably; how educational programs and policies, regardless of intent, reproduce stratified social relations; how schools institutionalize those with whom they come into contact; and how individuals react (e.g., resistance of acquiescence) to such social and institutional forces. (Diem et al, pp.1072-3)

After Denscombe's (2014) content analysis reveals the values of policy documentation, critical policy analysis turns to describing the complexities of educational policy, which in the case of STEM education in Australia, come with a lack of definitional clarity and implementation advice.

3.5.1 Implications for a lack of definitional clarity of STEM Education

There appears to be significant difference between policy rhetoric and practiced reality throughout STEM education enactment in Queensland schools (Diem et al., 2014), which stems from a lack of established definitional clarity. Shown below in Figure 5 is an overview of the argument that will be presented, herein. Discussed in section 3.5.1 will be the lack of definitional clarity and lack of clear enactment advice, with current and best practiced discussed in subsequent chapters.

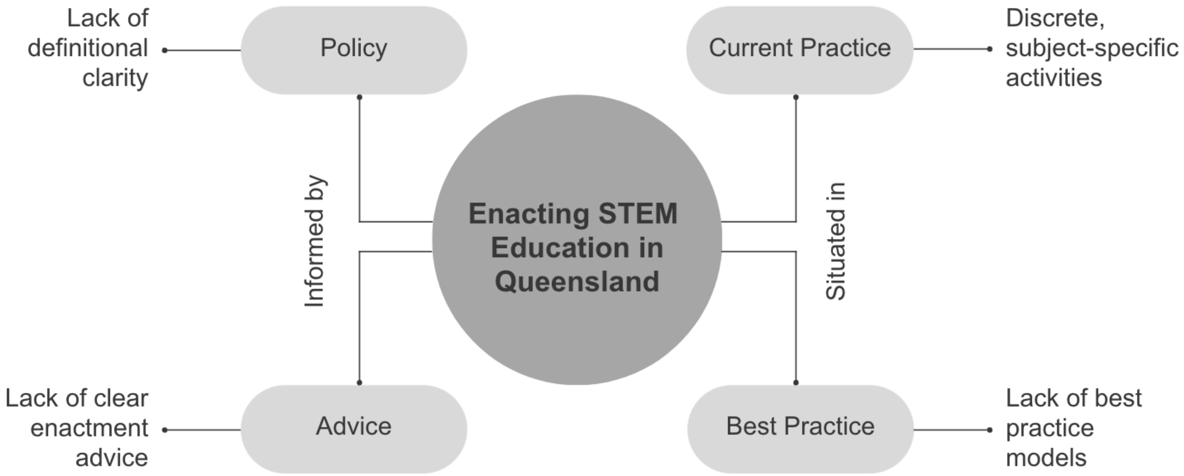

Figure 5. *Implications for enacting STEM Education in Queensland.*

3.5.1.1 Lack of definitional clarity in policy.

STEM education is commonly recognised as a national focus for Australia (ACARA, 2016a; Education Council, 2015; OCS, 2014), despite there being no clear consensus about how the term 'STEM education' is defined in either public or private sector publications analysed herein. Currently, there exists a continuum of definitions, ranging from an acronym that simply refers to a suite of individual subjects, to a highly integrated definition where each facet exists symbiotically within an ecosystem of transdisciplinary knowledge (Barkatsas, Carr & Cooper, 2019; English, 2017; Fraser, Earle & Fitzallen, 2019; Honey, et al., 2014; Lowrie et al., 2017; Rosicka, 2016; Vasquez, 2014). Many policy or framework documents refer to the National STEM School Education Strategy (NSSES) (Education Council, 2015) as the foundational definition from which to build. This publication defines STEM Education as "a term used to refer collectively to the teaching of the disciplines within its umbrella – science, technology, engineering and mathematics – and also to a cross-disciplinary approach to teaching that increases student interest in STEM related fields and improves students' problem solving and critical analysis skills" (Education Council, 2015, p. 5). Perhaps intentionally, the broad scope that appears to be the root of the collective policy language tolerates many of the more refined definitions that can be found in the documentation that formed part of this policy analysis.

Distilling an agreed definition of ‘STEM education’ from the policy documents reviewed, herein, is a complex notion. Seminal publications from a range of authoritative voices do not present a clear, unified definition. Some policy documents refer to a segregated definition of S.T.E.M., where the acronym is referring to a suite of discipline-based subjects, suggesting

> Science, Technologies, Engineering and Mathematics make up the STEM learning areas. The STEM learning areas are a key national focus for school education in Australia and are critical to equip students to engage productively in a world of rapidly changing technology. (Education Council, 2019, p. 15)

Other documents refer to both discipline-based and cross-discipline definitions of STEM, where the four areas are taught together, usually through a problem-solving pedagogy. For example, one definition found in the policy review states,

> STEM education is a term used to refer collectively to the teaching of the disciplines within its umbrella – science, technology, engineering and mathematics – and also to a cross-disciplinary approach to teaching that increases student interest in STEM related fields and improves students' problem solving and critical analysis skills. (Education Council, 2015, p. 5).

Similarly, references to both discipline-based and cross-discipline teaching of STEM can be found in the STEM Connections Report (ACARA, 2016a) which suggests that “STEM knowledge, understanding and skills are strengthened when connections between learning areas are identified and enriched when learning areas combine to find authentic learning opportunities for students to answer an identified problem or in the creation of a solution” (p. 6). Outside of national interests, prominent research suggests an integrated approach to STEM is the most productive way to define STEM education. Such an approach should involve teaching knowledge and skills from each of the disciplines together, or at least linking two or more learning areas to each other (English, 2016). In this view, one of the key aims of integrated STEM is to demonstrate how STEM skills can be applied to authentic problem solving (English, 2016; Honey et al., 2014; Lowrie et al., 2017). According to Helmane and Briska (2017), at the end of the spectrum of integration lies the concept of ‘transdisciplinary

STEM'. English (2016) defines a transdisciplinary approach to STEM implementation as one "where knowledge and skills from two or more disciplines are applied to real-world problems and projects with the aim of shaping the total learning experience" (p.1). Advice on how to implement or enact a transdisciplinary approach though, is not readily available to schools and teachers.

Following the 2013 release of the National STEM strategy (OCS, 2013), the Australian government clearly signalled STEM education to be a national priority with ongoing significance to Australia's future, with a particular focus on increased enrolments and performance in Science, Technology, Engineering and Mathematics (DESE, 2019; Education Council, 2015). As the policy then developed over time, key to this priority is the sentiment that Australian students should excel in these subjects at a secondary and tertiary level (ACARA, 2016a; DESE, 2016; Education Council, 2015). To excel in these subjects, government documentation points to a need for increased enrolments and performance in Science, Technology, Engineering and Mathematics subjects by students at a secondary and tertiary level (DESE, 2016; Education Council, 2015; ACARA, 2016). The National STEM Education Resources Toolkit (DESE, 2020b) is the only source that provides a clear strategy for teachers and schools to implement a STEM agenda in a school setting. This online resource mentions two clear priorities in relation to implementing a STEM agenda in schools: "[1] Get students more excited about and [2] interested in STEM education at school. This forms part of the broad concept of student engagement and improve students' STEM knowledge and skills. This forms part of the broad concept of student achievement" (DESE, 2020b). Thesis priorities necessitate, then, a review of descriptions of STEM education in Australian policy, and to draw comparisons between the STEM definitions used within both public and private sectors operating at the national level.

Highlighting a national focus on STEM education, Australian Curriculum documentation states that STEM Education is "central to a well-rounded education" (ACARA, 2016a, p. 4). However at this national level, the Education Council defines STEM education with the same, broad-scoped, spectrum as previously mentioned, suggesting that "STEM Education is a term used to refer collectively to the teaching of the disciplines within its umbrella – science, technology, engineering and mathematics – and also to a cross-disciplinary approach to teaching that increases student interest in STEM-related fields and improves students' problem solving and critical analysis skills" (Education Council, 2015, p. 5). The notion of discipline-based STEM education is further supported by the Quality Schools, Quality Outcomes publication (DESE, 2016), which clearly states that the Australian Government is committed to improving STEM education in schools but diminishes the definition of STEM education to "skills drawn from each of the 4 key learning areas" (p. 6). To contrast with this, Australian Curriculum documentation acknowledges an integrated STEM approach, and even states a range of benefits of approaching it in this manner (ACARA, 2016c). This includes three suggested modes for delivery: single elective classes, multiple classes with subject overlap or separate classes with a common project (ACARA, 2016a, p. 8). Within national policy, there appears to be variability in the definition of STEM education and questions arise about success criteria for STEM initiatives being implemented and/or enacted in school settings.

3.5.1.2 Lack of enactment advice.

Recently, an evaluation of the National Innovation and Science Agenda was published by the Department of Education (DET) (2020). Listed in the key evaluation findings is the notion that most STEM initiatives "achieved their objective through increased STEM confidence and engagement in their target audience" (DET, 2020, p.3). However, the report then goes on to state that "most initiatives have teachers as their target audience" (DET, 2020, p.3). This suggests that most STEM initiatives have been targeting teachers rather than students. In the summary of recommendations, this same report suggests that policy documents "continue to define STEM broadly but promote approaches that build general capabilities and incorporate real world experiences" (DET, 2020, p. 20). It is argued that an important step in this process will be "building a robust and consistent national evidence base on what success looks like in STEM education" (DET, 2020, p. 20). These statements, then, further solidify the notion that in the current Australian context, STEM education does not have an agreed definition, nor does it have clear success criteria to facilitate systematic evaluation of the various STEM initiatives that have been funded and implemented to date. To further understand how these constructs may translate to teachers and students in classrooms, a closer examination of policy in the private sector was conducted.

In 2016, the Australian Council for Educational Research (ACER) conducted a review of STEM education research with the priority of translating it into short messages for teachers implementing STEM Education initiatives in classrooms. The key definition of STEM education used in this review is “teaching and learning between/among any two or more of the STEM subject areas and/or between a STEM subject and a non-STEM subject such as the Arts” (Rosicka, 2016, p. 2). It was further recognised that while it is necessary to teach skills from individual learning areas, reports showed the benefits of integration, which include improved problem-solving skills, increased motivation and improved Maths and Science outcomes (Rosicka, 2016; Blackley & Howell, 2015; English & King 2015). In contrast to this discipline-based definition, other publications recognise while it is necessary to teach skills from individual learning areas, there are other benefits of interdisciplinary pedagogies, which include improved problem-solving skills, increased motivation and improved Maths and Science outcomes (Rosicka, 2016; Blackley & Howell, 2015; English & King 2015). A second review conducted by ACER focussed on challenges in STEM learning in Australian Schools (Timms et al., 2018). This second review clearly states that “STEM education has several different definitions, or it encompasses a continuum of concepts under the roof of… the ‘house of STEM’” (p. 2). Despite this variability, many of the policy documents share a common aim, of wanting young Australians to increase their engagement and achievement in STEM fields. This aim is reflected in statements such as “the primary aim of the national strategy is to support all young people to become more STEM capable” (Education Council, 2015, p. 5). When this literature concerned with STEM Education in Australia is synthesised, it seems there is little consensus on a definition of STEM education. However, the implementation advice and success criteria — whilst lacking specificity for schools and teachers — point to the merits of a cross-disciplinary, rather than discipline-based, implementation of STEM Education.

3.5.2 Using critical discourse analysis to examine implications for teachers of a lack of formal curriculum-based STEM Education implementation advice

Across the policy assemblage reviewed, STEM education implementation for schools in Australia is highly variable, with suggestions and guidance dependent upon on the definition of STEM education that is privileged by the policy. When privileging a discipline-based definition of STEM education, implementation advice is usually generalised. For example, Watt's (2017) review of the Australian government's 2013 publication "The Coalition's Policy for Schools: Students First" indicated that it presented a discipline-based description of STEM, with promises to "restore focus on science, technology, engineering and mathematics in primary and secondary schools" (p. 11), with success measured by an increasing number of students studying science and mathematics subjects specifically. There were specific strategies listed to achieve this goal, including establishing an advisory board, making these subjects compulsory in senior secondary years and maintain funding for a primary school-based program: Primary Connections.

In contrast, when considering cross-discipline definitions of STEM education, policy documents tend to present multiple approaches to implementing STEM Education including partnership programs, integrated teaching and project-based teaching of STEM. Lowrie et al. (2017) suggest that cross-discipline approaches usually incorporate problem-based, project-based or inquiry-based learning strategies which enable students to explore, come to their own understandings and solve their own problems. The National STEM Education Resources Toolkit (DESE, 2020b) lists nine principles to achieve a cross-discipline implementation of STEM education: inquiry-based learning, solving real world problems, teaching of integrated STEM learning, creating partnerships between schools, industry and community, engaging parents and families, using technology as an enabler, differentiation for different year levels and linking STEM education to 21st century learning. Across the assemblage of policy, there are a broad range of potential approaches to implementing STEM education in Australian schools, however, the advice is dependent on the definition of STEM that has been privileged by the document.

Given the range of possible approaches to the implementation of STEM Education, it is possible to see how teachers and schools who are looking to implement a STEM program in their context can become confused or even overwhelmed when seeking an evidence-informed approach to STEM implementation in the various classroom contexts that exist across Australia. STEM teachers, charged with enacting policy at the classroom level, seem to be carrying the weight of a nation. With towering goals such as “prepar[ing] a skilled and dynamic STEM workforce” (OCS, 2014, p. 6) and “equip[ping] students to engage productively in a world of rapidly changing technology” (DESE, 2019, p. 10) emanating from some of the highest educational authorities in the nation, the pressure on teachers could be seen as overwhelming. For example, teachers are informed that “[t]he Australian Government has committed to improving STEM education in schools with the aim of ensuring that young Australians are prepared for the jobs for the future” (DESE, 2016, p. 6), and are then tasked with creating programs that prepare students for future national productivity demands to withstand global competition (Education Council, 2019, p. 3). With such immense imperatives to enact, it is critical to understand the role of a STEM teacher in implementing STEM education in an Australian context.

Across the policy assemblage analysed herein, STEM teachers are most commonly characterised as people who either teach a discrete STEM subject or are an expert in a subject from the STEM suite. For instance, the Education Council (2019) points out that teachers can either *work as* a STEM teacher, including teachers who may be working outside their qualification fields, or *qualify as* a STEM teacher, by undertaking teaching qualifications after a degree in a specialist area. In either case, the STEM teacher is described as having specialist knowledge in one of the STEM subjects (Education Council, 2019, p. 19), clearly linking to their conceptual knowledge within a discrete field, rather than expertise in knowledge processes (for example, problem-solving) that would align with a more cross-disciplinary definition of STEM education as highlighted within the policy assemblage reviewed, herein.

Clear and specific guidance about the responsibility of STEM teachers enacting STEM education can also be difficult to ascertain from policy documentation. As noted in the National STEM School Education Strategy, teachers are asked to “improve student aspiration, engagement and performance” (Education Council, 2015, p. 25) but, as already established, these policy documents lack specific guidance of how teachers might do so. For example, the current curriculum documents, which Queensland teachers use to inform day-to-day activities and pedagogy (ACARA,2018a; QCAA, 2018), do not include any references to a cross-discipline definition of STEM within the mandated content and assessment, despite being referenced as important for strengthening knowledge, understanding and skills in the STEM Connections Report (ACARA, 2016). It seems that the pattern of Australian curriculum and assessment, which generally does not include explicit STEM advice, “sends a message to schools that STEM is not fully embraced and so teaching will reflect that” (Education Council, 2019, p. 19). Consequently, navigating the complex terrain of teaching, learning and assessment in schools may have relegated STEM education to the extra-curricular spaces of schooling, where there is less risk associated with implementation.

3.6 Conclusions

The content analysis and critical policy analysis conducted, herein, has endeavoured to outline the policy-scape of STEM education in public and private sector publications and the definition and reasoning for STEM education in Queensland, Australia. Alongside this, the nature and scope of STEM education implementation advice provided through policy to support the role of schools and teachers implementing and/or enacting STEM Education initiatives has been considered. The findings of the content analysis show that phrases related to the concept domain “Definition” accounted for a total of 56.33% of all coded units, the highest of all concept domains. Competing phrases related to the definition of STEM education, “Discipline-based STEM” (12.14%) and “Cross-discipline STEM” (8.53%), ranked first and third of all coded units, with only “STEM futures” (9.04%) sitting in between them. The “Implementation” concept domain accounted for a total of 33.33% of all coded units, however when listing all phrases in order of occurrence, the first instance of “Implementation” appears in 7th position, with “STEM engagement” accounting for only 6.20% of all occurrences. As such, it was demonstrated that a definitive, agreed and established description of ‘STEM education’ does not exist in policy. Instead, both governmental departments and research agencies employ broad definitions that allow for a highly variable range of implementation strategies to be classified as STEM education. It is argued here that this variability provides little guidance or support for teachers working to enact STEM curriculum innovations.

STEM education seems to be amid a change journey, with many definitions and pedagogies being trialled across primary and secondary school settings (ACARA, 2016). Whilst there is inherent merit in allowing for creative and innovative expressions of STEM education, it is argued, herein, that a lack of definitional clarity does create obscurity and makes it difficult for schools and teachers to select evidence-informed approaches to support the implementation and/or enactment of STEM education initiatives in their contexts. This position is supported by Watt (2017) who states that “[a] strong evidence base for STEM should be built by national reports charting changes in data indicators and sharing and synthesising research and evaluation” (p.11). Without such evidence it is likely that the approaches with the greatest success will likely gain attention, diffuse and be widely adopted. Furthermore, “better guidance is needed for schools and teachers to determine which approaches work best for different purposes and student cohorts” (Education Council, 2015, p. 10). Rosicka’s (2016) review revealed several gaps within STEM education research, most notably “to form and use a coherent, shared definition of STEM education” and “to conduct more research into the impact on student outcomes of integrated STEM education programs” (p. 6). There is consensus between policies, however, that student performances in STEM, regardless of the definition, need to improve. Policies suggest this improvement can be measured by increased enrolments in STEM subjects or increased outcomes of students already enrolled in STEM subjects. Regardless of this common policy goal, there is no clear consensus in policy how to implement and/or enact STEM education in the primary and middle school years such that enactment leads to this goal in senior secondary years of schooling. Without a clear consensus, success measures can be biased or ambiguous.

Clarity around the roles and responsibilities of STEM teachers and their qualifications to enact STEM education in the classroom are also difficult to determine. Whilst there is agreement that the teaching of STEM is important and therefore a high priority for Australia's future (ACARA, 2016; Department of Education and Training, 2017; Education Council, 2015, 2019; OCS, 2013, 2014; QCAA, 2019), beyond this sentiment there exists a continuum of conceptual understanding of what STEM is, who should teach it and how it should be taught. In general, it seems that a description of a STEM teacher can be reduced to a subject expert, who has developed knowledge and expertise in a specific area, a definition that clearly subscribes to a separated, disciplinary definition of STEM (Education Council, 2019). The role of teachers presented by the Education Council's (2015) National STEM School Education Strategy, whilst tolerating a spectrum of definitions, can create further confusion for teachers themselves at the implementation and/or enactment stage, as teachers must decide which version of the STEM definition to align their work with – discipline-based or cross-disciplinary. How, then, can STEM teachers implement and/or enact a cross-disciplinary or transdisciplinary program when it is their knowledge as a discrete subject expert that policy sees as underpinning their ability to 'teach STEM'?

Enacting STEM Education policy, then, becomes a matter for further debate, with many open-ended examples of STEM education enacted in classrooms in the absence of limited implementation advice, particularly in terms of mandated curriculum. In Queensland, Australia, at both the national and state levels, STEM is not a mandated learning area. Instead, STEM education policy classifies individual subjects within STEM disciplines as 'STEM'. Consequently, in what is already seen as an overcrowded curriculum, cross-discipline, integrated or transdisciplinary STEM is often relegated to the margins of school practice, with extra-curricular programs doing the work of addressing the STEM Education policy imperatives. A more formal approach to STEM Education can only be enacted if schools navigate this complex policy terrain and create the space, time and resources to do so.

In response to Research Question One, which asks "What are the core constructs of STEM education for Queensland schools, as described by national and state education policy?", the answer is still unclear. The high degree of variation in definitions and implementation advice seem to point towards the overarching purpose of STEM education as the only definitive core construct. The assemblage of policies analysed herein propose that the purpose of STEM education is to prepare students to participate in dynamic workplaces of the future, as well as being able to engage productively in a rapidly changing world (DESE, 2019; OCS, 2014). Therefore, with the weight of a nation's future on their shoulders, STEM teachers are charged with enacting a national imperative that is only ambiguously defined by policy and lacking in either specific or best-practice advice for policy implementation or curriculum enactment.

Whilst it is possible to extract a working definition of what STEM should look like for young Queenslanders from policy documents and expert sources (ACARA, 2015; ACARA, 2016a; ACARA, 2016b; QCAA, 2017; QCAA, 2020; QCAA 2021a; QCAA, 2021b; OCS, 2013, 2014), researched cases of STEM enactment in Queensland are generally set in primary school contexts, characterise their programs as integrated or interdisciplinary, and exist within activities or short units. Therefore, it is the intention of this study, herein, to present an exploratory case of transdisciplinary STEM enactment in a secondary school in the Queensland context. The case focuses on a specific approach to enactment of a transdisciplinary (Helmane & Briska, 2017, p.11) STEM curriculum program which is aligned with the characteristics of transdisciplinary STEM education. The research seeks to evaluate the program's effectiveness at enacting a transdisciplinary STEM curriculum program, that is clearly aligned to STEM education policy agenda relevant to the Queensland context, in an independent Queensland secondary school. The goal is to draw conclusions that may be transferable to different contexts, and to add to the body of practical knowledge surrounding STEM enactment advice.

Having established that there is a lack of clarity in the policy landscape to inform the development and enactment of STEM curriculum innovation in Queensland schools, the research herein turns to the next phase of its methodological approach. The Parklands Christian College enactment strategy is an attempt to enact the conceptualisation of STEM education priorities identified in the STEM Education policy assemblage reviewed in Chapter 3. Chapter 4 will describe the Parklands Christian College conceptualisation, development and subsequent enactment of a STEM subject within curriculum time (i.e., not an extra-curricular program) in a secondary school context, utilising a transdisciplinary approach.

Chapter 4: Overview of the Parklands Christian College STEM Education Curriculum Innovation

4.1 Parklands Christian College

Parklands Christian College is an independent, faith-based school situated in Park Ridge, Queensland. It is a Foundation to Year 12 school, with approximately 650 enrolled students in total and approximately 300 students enrolled in the secondary school (Years 7 to 12).

4.2 STEM Studies at Parklands Christian College

STEM Studies is a timetabled elective subject, that can be chosen by students in Year 9 and subsequently completed over a two-year course to the end of Year 10. In Year 9, STEM Studies has three lessons per week, each 50 minutes, and in Year 10, this extends to four 50-minute lessons per week. The number of teachers involved in teaching STEM Studies each year fluctuates with enrolment numbers, from 2017 to 2020 there were two active teachers; in 2021 and 2022 there were three. Across the course of STEM Studies enactment at Parklands Christian College, there have been a total of five different teachers who have taught the class, who specialise in a range of discipline areas such as Mathematics, Science, Engineering, Design and Technologies. The role of the teacher in the STEM Studies classroom is characterised as an expert facilitator. Teachers bring expert knowledge from their disciplines as a resource students can draw on, and function as a facilitator within project work, rather than instructor of discipline-specific content. Team teaching is facilitated in the STEM Studies classes. Classes that are timetabled at the same time (for example, two Year 10 classes) join together in one space, so that two teachers can facilitate the whole cohort together.

4.3 Curriculum and Assessment

Parklands Christian College characterises the STEM Studies curriculum innovation as an applied, transdisciplinary approach to STEM education. Over the two-year course, students engage in student-led, problem-driven projects. STEM Studies at Parklands Christian College begins with discrete discipline knowledge and skills, that are formally taught and assessed within the other subjects that students participate in, such as Mathematics and Science. The 21st Century Skills (QCAA, 2019) and the General Capabilities (ACARA, 2018b) are explicitly taught and modelled, as well as built into learning activities. PCC's ideological position of STEM education and an excerpt of the course structure of the Parklands Christian College 2022 STEM Studies work program are provided in Appendix 8. Students are given multiple opportunities to explore their understandings of self, the way they work as well as how to engage effectively in dynamic teams. The culmination of this work is when relevant, authentic and contextual problems are either introduced to students or they are asked to seek them for themselves. For example, after identifying and clearly framing real-world problems, students engage in an iterative form of problem solving, where they investigate, manipulate, design and model solutions before enacting them in the community. In this way, the curriculum innovation has been characterised as transdisciplinary, as it hinges on holistic responses to problems, that utilise understandings of the human condition as well as discrete subject knowledge and skills in authentic contexts. This approach aligns with Helmane and Briska's (2017) definition of transdisciplinary approaches to curriculum development.

Assessment in STEM Studies includes both formative and summative assessment, and the alignment of these assessment pieces with the intended curriculum is detailed in the attached PCC STEM Studies work program (Appendix 8). Formative assessment is enacted through "Student Conferences", which usually occur mid-project. Groups of students give a multi-modal project update to the class and other stakeholders and receive critical feedback from the audience. Feedback is collected through digital surveys and is collated by teachers to ensure any advice given is useful. Summative assessment is enacted through two key assessment items, "Project Evaluations" and "Student Interviews". Project evaluations are formal written documents that evaluate the effectiveness of a fully enacted project, through a structured reporting process. Student interviews take the form of a one-to-one interview between student and teacher, at the end of each term. Before attending their interview, students are required to complete a self-evaluation form, where they mark, with justification, their performance for term, and compile a portfolio of supporting evidence. During the interview, the student and teacher negotiate an overall grade, based on the evidence and justification the student provides against marking criteria, in a similar format to a performance evaluation in a workplace. Task-specific criteria were developed for each assessment style and project, derived from ACARA's (2018b) General Capabilities, under three key marking categories "Thinking Skills" (inclusive of Critical Thinking and Creative Thinking), "Interpersonal Skills" (inclusive of Personal and Social Capabilities, Ethical Understandings and Intercultural Understandings) and "ICT Skills" (inclusive of Information and Communication Technologies); please see Appendix 9 for a sample instrument. In the earliest phases of enactment, students were marked against school-developed criteria based on QCAA's (2019) 21st century skills, however, the General Capabilities gave more scope for students to provide physical evidence of their learning. By using these assessment strategies, the Parklands Christian College curriculum innovation aims to mirror workplace ready practices of assessing, communicating and celebrating growth, progress and success.

4.4 Resources

The Parklands Christian College STEM Studies subject was first enacted without the purchase or use of any special resources. In the earliest phase of enactment in 2017, an existing computer lab and technologies shed were used as classroom spaces. The program was supported financially through the provision of two teachers and two teaching spaces allocated to a single class of only seven students. After the first year of enactment, enrolments grew to over twenty students, meaning the student to teacher ratio improved. Currently in 2022, the class operates out of fit-for-purpose teaching space, called a "Collaborative Centre". The teaching space is not especially remarkable, but includes equipment such as movable furniture, linoleum floors and supplies of generic prototyping equipment such as cardboard and balsa wood. It also includes three 3D printers. If students would like to access further resources that the school has onsite, for example a laser cutter or a particular teacher's expertise, they are able to do this through an appointment booking system. The Collaborative Centre is used for other similar subjects such as Design and Engineering classes.

4.5 Phases of Enactment

The STEM Studies curriculum innovation has been enacted at Parklands Christian College since 2017. To provide clarity and understanding of the phases of enactment, a timeline has been constructed with brief points about key events that occurred in each phase:

1. Pre-enactment phase (Planning focus): 2016
    - Research and development of the Parklands Christian College definition of STEM education
    - Planning the curriculum innovation
    - Approval to enact granted by leadership staff
2. Early enactment phase (Year 1): 2017
    - First cohort of students (seven students in total) in Year 10 only
    - Team teaching first introduced with two teachers acting as expert facilitators (HOD Maths/Science and HOD Design/Technologies)
3. Middle enactment phase (Years 2 and 3): 2018 – 2019
    - Refining of all aspects of the curriculum innovation including learning sequence, assessment and reporting procedures
    - 2018: an onsite professional learning STEM Conference was developed and delivered to Parklands Christian College STEM Studies students, as well as invited students and staff from other schools from the local area
    - 2019: STEM classes were offered to Year 9 for the first time
    - 2019: The second annual STEM Conference was delivered to Parklands Christian College STEM Studies students
4. Recent enactment phase (Year 4): 2020
    - Refining all aspects of the curriculum innovation including learning sequence, assessment and reporting procedures, based on anecdotal evidence of teaching and learning
5. Recent enactment phase (Evaluative focus): 2021-2022
    - 2021: the first new teacher was added to the teaching staff of STEM Studies
    - 2022: two further new teachers were added to the teaching staff of STEM Studies

The researcher of this case study is an actor within the STEM education curriculum innovation, enacted at Parklands Christian College. The researcher was involved in the STEM Studies program at PCC from its conceptualisation, participating as a member of the teaching staff with involvement in research and development and classroom teaching in every phase of enactment. Having provided an overview of the contextual details of the STEM education enactment case, Chapter 5 will now present findings from an autoethnographical record of enactment and semi-structured interviews. The findings are presented and analysed in the next chapter to provide insights from people who worked to navigate the STEM education policy-scape in this specific case of STEM Education implementation at Parklands Christian College.

Chapter 5: Findings: Autoethnography and Semi-Structured Interviews

5.1 Introduction

The following chapter reports findings from the analysis of autoethnography data as well as semi-structured interview data collected from interviews with four staff members at Parklands Christian College [PCC], who were involved in the STEM Studies subject enactment. It then triangulates data with themes derived from the findings presented in Chapter 4: Policy Analysis. The triangulated findings from policy analysis, autoethnography and semi-structured interview present some resolution to Research Question Two ‘How is one example of middle-school STEM curriculum conceptualised at one independent school (PCC) in Queensland?’.

As described in Chapter 2, the autoethnography and semi-structured interview data were analysed using phronetic iterative analysis (PIA) (Tracey, 2019). PIA is a method that requires the researcher to move through iterative cycles of analysis. Consequently the findings of the analysis are layered. Therefore, results of the PIA are presented as a series of tables organised according to secondary codes (Tracey, 2019; see Chapter 3, Table 4). Each table demonstrates the differences in perspectives of staff involved in STEM curriculum enactment at the case study site in accordance with each of the layers of coding. The autoethnographical data represents the viewpoint of the principal researcher, who was part of the enactment team at PCC. The semi-structured interview data was divided into two key perspectives, that of the “Administration” or leadership staff at the case study site, and that of the “Teaching Staff” who were involved in the enactment. This distinction emerged during the early stages of phronetic iterative analysis, as it became apparent that the separated groupings provided valuable differences in perspective of policy and enactment.

My role as a member of teaching staff began with highlighting to other staff member the policy imperatives of STEM education. From there, my role evolved to be one of two leaders within the curriculum innovation, alongside another member of the STEM Studies teaching staff. Consequently, analysing my own reflections through autoethnography and triangulating those findings against themes emerging from other key staff members collected during semi-structured interviews was critical to understanding the barriers and enablers shaping the enactment of the STEM Studies subject at PCC. There are a range of limitations associated with using autoethnography as a methodological tool, including retrospective consent (Tolich, 2010), but given those limitations it has been included to represent my positionality in the project. All persons mentioned in the autoethnographical account were invited to share their perspectives through the semi-structured interview process.

5.2 Results: Autoethnographic data and semi-structured interview data

To systematically review results, discussions have been structured using primary coding domains, secondary coding phrases and chronological enactment phases as organisers (see Figure 6).

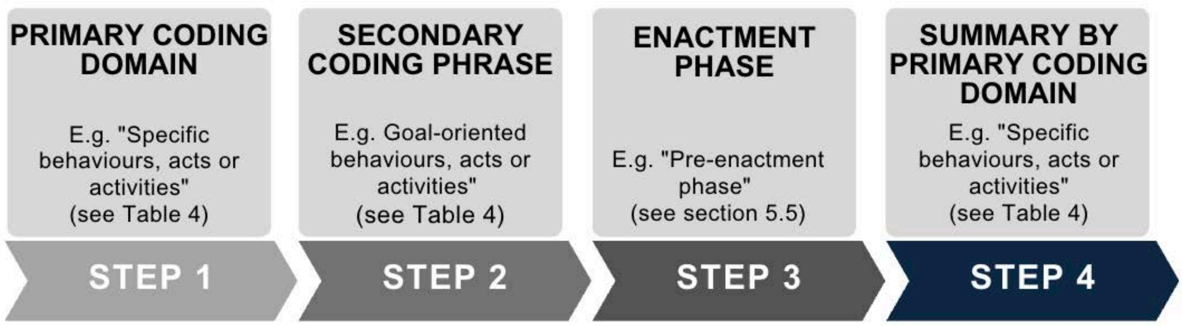

Figure 6. *Discussion of results organised by primary coding domain, secondary coding phrase and then chronological enactment phase.*

A full list of analytic memos can be found in Appendices 2 to 4, with excerpts being listed throughout the following results sections in tables. Appendix 2 shows quotes from the coded autoethnography entries, arranged in chronological order of enactment phases. Appendix 3 shows key quotes from the coded semi-structured interview transcripts, from an administrative staff perspective. Appendix 4 shows key quotes from the coded interview transcripts, from a teaching staff perspective.

5.3 Results of Primary Coding Domain: Specific Behaviours, Acts or Activities in Enacting the STEM Curriculum Innovation at PCC

The first Primary Coding Domain aims to illustrate the specific behaviours, acts and activities critical to enacting STEM at PCC (Tracey, 2019). Within this primary coding domain, the following Secondary Coding Domains were established:

- Goal-oriented behaviours, acts or activities
- Emotion-oriented behaviours, acts or activities (Tracey, 2019).

Analysis of the autoethnography and semi-structured interview data is listed in sections below, by secondary coding domains. Within each section, excerpts of primary data related to the secondary domain being discussed are presented in tables: extracts of autoethnography data and extracts of semi-structured interview data. Analysis is then organised by chronological enactment phases, to demonstrate the range of behaviours, acts and activities that have been identified at each developmental stage of this case. Not all enactment phases are discussed in relation to each secondary coding domain; only those phases that were co-located in the data.

5.3.1 Secondary Coding Domain: Goal-oriented behaviours, acts or activities

The results in this section examine results in the secondary coding domain of goal oriented behaviours, acts and activities, for both the autoethnography and semi-structured interview data. Goal oriented behaviours, acts and activities describe actions taken by actors within the enactment strategy, for a specific goal or purpose (Tracey, 2019). Within this case study, the goals included designing a timetabled STEM subject for Years 9 and 10 students; having the subject approved for implementation; ensuring the types of problems that students addressed within the subject were authentic and meaningful; and, leading change in STEM curriculum enactment. Excerpts of primary data describing these actions are listed below in Table 9 (autoethnographic data), Table 10 (semi-structure interview data: administration perspective) and Table 11 (semi-structured interview data: teaching staff perspective). The actions utilised to meet these goals are described below, in chronological order of enactment phase.

Table 9.

Autoethnographic data: goal-oriented behaviours, acts or activities

Tertiary code	Quotes
Negotiating	"… We were noticing that students kept wanting to solve school-based problems like litter or uniforms, and weren't thinking beyond the classroom. I really felt that this was due to their socialisation into assessment responses in schools - they hadn't yet grasped the idea that they had free and unlimited choice." (Entry D, 2021)
Leading	"… I committed to answering the question for myself, WHAT IS STEM? I started… reading everything I could find related to STEM in Australia. I felt convicted by the Office of the Chief Scientist and Education Council publications in particular, as they felt like authoritative voices" (Entry B, 2021) **"…**it was a good representation of what STEM should be, as it focussed on thinking skills. Hearing a keynote speaker… [speaking] about futuristic knowledge economies [and the] need for students with thinking skills. This was really when I started to ideate." (Entry B, 2021) **"…i**nspired by future thinking skills, changing educational paradigms, and good some examples of STEM. After reading and writing, I felt like I had a good idea going forward. I wanted to implement a new type of elective subject with our Year 10 students." (Entry B, 2021) "… [the] priorities were to 1) get [teachers] to understand the heart of why [we] designed the program this way (in response to enacting policy rather than implementing curriculum); 2) allow [new teachers] time to watch and integrate into the unique ways of working (transdisciplinary meaning organically seeking/learning/using discipline based knowledge and skills to actively solve a contextual problem) and increase [new teachers'] confidence in being able to teach within this different pedagogy." (Entry J, 2021)

Table 10.

Semi-structured interview data: administration perspective of goal-oriented behaviours, acts or activities

Tertiary code	Quotes
Negotiating	"Initially the types of problems we thought students would engage with was quite different to what they were engaging with… we realized students needed help identifying actual wicked problems and then framing those problems before solving them" (A1, p. 5) During early implementation, problems students wanted to solve were described by A1 as "very here-focussed rather than those bigger picture, real-world, meaningful problems" (A1, p. 5) In reference to having to assist students in framing up problems, a critical element of STEM enactment at PCC, A1 describes it as "something that we maybe didn't - I certainly didn't anticipate" (A1, p. 6)
Leading	"It's a priority" (A1, p. 4) – in reference to why it was approved to run as a subject within curriculum time. Administration saw the proposal for the activity as something important that was missing from the students' current experience of school.

Table 11.

Semi-structured interview data: teaching staff perspective of goal-oriented behaviours, acts or activities

Tertiary code	Quotes
Leading	"… it's very much about getting a feeling for where those students are at and adjusting it [the teaching and learning approach]… some of them may need a bit more of something" (T1, p. 5). "… very much back and forth between us and the students. Lots of communication… Lots of feedback… [and] short intervals, just to keep the temperature of the room". (T1, p. 6) "let them get off track sometimes as well, because that's a good thing to learn. There is an experience in there as well" (T1, p. 6). "I like to think, what are the steps I would go through there, and then try to get them to think about those same sorts of things" (T1, p. 7). "What's it like? Where's everyone at? Are you understanding? Are you on track? Have you deviated by far? Do I need to intervene a bit more, or do I need to give you a little bit more freedom?" (T1, p. 6) "I feel that those students, they like structure… we have to change our approach a little bit and just work a lot closer with them. Maybe giving them a little bit more guidance, a little bit more scaffolding, and slowly ease them towards the… open-endedness" (T1, p. 7). "… give them a bit of scaffolding around feeling secure so that they think, "Oh, actually I have got a bit of structure, it's not as bad as I thought." As they get more and more comfortable, we can take away [the scaffolding]." (T1, p. 8) "By exposing them to these problems and allowing them to come up with their own solutions and… their own problems, we're changing the way that they think, and then they can apply that across all spectrums. Whether it's another subject, whether it's when they go home, out into the community. As you're changing their brain, they take their brain with them everywhere" (T1, p. 9) "…one of the things we did… was expose them to… MBTI. And we talked about working in groups and solving problems in teams. And having those different skills of people that you need to solve problems. That you might need to engage with different people sometimes. We…try and get them to think about… maybe don't always go with your friends." (T1, p. 10).

In the pre-enactment phase, the teachers and administrators involved were focused largely on goals and demonstrated goal-setting behaviours. The first action that occurred in the PCC enactment of STEM curriculum was a personal connection between the policy conceptualisation of STEM and the teaching staff's development of an enactment strategy that met the overarching purpose of STEM education in Australia. Federal policy describes STEM education in Australia as "…deep knowledge of a subject, creativity, problem-solving, critical thinking and communication skills… [that] are relevant to an increasingly wide range of occupations. They will be part of the foundation of adaptive and nimble workplaces of the future, and that STEM skills are the lifeblood of emerging knowledge-based industries such as biotechnology" (OCS, 2014, p. 7). Armed with this perception of STEM, the researcher notes that they felt

> …inspired by future thinking skills, changing educational paradigms, and good some examples of STEM. After reading and writing, I felt like I had a good idea going forward. I wanted to implement a new type of elective subject with our Year 10 students. (Entry B, 2021)

Administrative staff at the case study site expressed that the STEM Studies subject, as proposed by teaching staff, was a priority for enactment as it provided something that was currently missing from the students' experience of school (see Table 10). In reference to why the STEM Studies program was approved for implementation at the case study site, administration staff saw the proposal as a "priority" for PCC students (A1, p. 6).

Throughout the early enactment phase, goal-oriented behaviours were demonstrated through rigorous negotiation. The PCC enactment strategy values the authentic, contextual, problem-based approach that is outlined in policy documentation. A1 (p. 4) and A2 (p. 5) both communicate student agency as a priority within the enactment strategy. Key actions that occurred during this phase were negotiations with staff and students around the types of problems that would be acceptable for students to address. The need to negotiate appropriate problem selection emerged as an issue in the early enactment years. For example, during 2017 and 2018, problems that students wanted to solve were described by A1 as "very here-focussed rather than those bigger picture, real-world, meaningful problems" (p. 5). "Initially the types of problems we thought students would engage with was quite different to what they were engaging with… we realised students needed help identifying actual wicked problems and then framing those problems before solving them" (A1, p. 5). In reference to having to assist students in framing up problems, a critical element of enactment within STEM Studies at PCC, A1 describes it as "something that we maybe didn't - I certainly didn't anticipate" (A1, p.

6). This need for negotiation around the framing of problems to address in the early years is further reinforced in autoethnographical data, where it is suggested:

… we were noticing that students kept wanting to solve school-based problems like litter or uniforms and weren't thinking beyond the classroom. I really felt that this was due to their socialisation into assessment responses in schools - they hadn't yet grasped the idea that they had free and unlimited choice. (Entry D, 2021)

In the guiding principles for schools to support STEM education, the Education Council (2015) asks schools to "connect STEM learning to solving real-world problems" (p. 11). STEM programs should be "using problem-based or inquiry approach to create solutions" (QCAA, 2017, p.1). From these two key documents, (Education Council, 2015; Queensland Curriculum and Assessment Authority, 2017) it is argued that an authentic, or real-world context alongside approaches such as connections to industrial partners, framing social challenges, problem-solving or future ways of working is critical to STEM initiatives.

The interview and autoethnographic data demonstrate some challenges associated with enacting these policy intentions with students in classrooms. Within the recent enactment phase, goal-oriented behaviours such as leading change were also displayed by the teaching staff. The PCC enactment strategy emphasised transdisciplinary approaches to teaching, learning and assessment, as opposed to simple, non-connected activities, a sentiment that was most obviously displayed by the pedagogical techniques that were utilised in the classroom. The pedagogical techniques employed in the PCC curriculum innovation provide distinguishing qualities of this approach to learning, from a direct instruction classroom. This approach represents leading a change in the way STEM education is enacted. Across the four interviews, responses that were categorised as goal-oriented behaviours included some specific techniques that teaching staff use in the classroom arose, that align with Helmane and Briska's (2017) characterisation of transdisciplinarity. A summary of these responses suggests there are five pedagogical techniques that are key to the STEM Studies classroom at PCC:

1. A responsive pedagogy that utilises open-ended questioning techniques to allow for real time flexibility
2. Exposing students to open-ended problem-solving later in the process

3. Troubleshooting and employing relational strategies to work with students who are disengaged from the process
4. Promoting and utilising understanding of self, teams and society as an important part in the problem-solving process
5. Solving problems related to real-world issues in an authentic manner

Each of these techniques will now be elaborated, in turn.

All staff interviewed, both teaching and administrative alike, identified the use of a responsive pedagogy within the STEM Studies classroom at PCC. In this case, responsive pedagogy could be characterised as the method and practice of responsively teaching students to engage with a new theoretical concept, a new skill, a situation or a problem. T1 suggests that to teach responsively is "…very much about getting a feeling for where those students are at and adjusting it [the teaching and learning approach] … some of them may need a bit more of something" (p. 5). This technique is "… very much back and forth between us and the students. Lots of communication… Lots of feedback… [and] short intervals, just to keep the temperature of the room" (T1, p. 6). In terms of how to respond to students' questions, needs or requests for assistance, T1 identifies that "I like to think, what are the steps I would go through there, and then try to get them to think about those same sorts of things" (T1, p. 7).

The act of training teachers to teach in this responsive, reflexive pedagogy has been an important part of the recent enactment phase. Autoethnographical data reflects on the process of onboarding a new teacher in the 4th year of enactment, suggesting that to successfully train teachers,

> … [the] priorities were to 1) get [teacher] to understand the heart of why I designed the program this way (in response to enacting policy rather than implementing curriculum); 2) allow [teacher] time to watch and integrate into the unique ways of working (transdisciplinary meaning organically seeking/learning/using discipline based knowledge and skills to actively solve a contextual problem) and increase [teacher]'s confidence in being able to teach within this different pedagogy. (Entry J, 2021)

Exposing students to open-ended problem solving emerged as a pedagogical technique in interview data from both teaching and administration staff. Open-ended problem-solving is an important part of a transdisciplinary STEM enactment strategy and is mentioned in many policy descriptions of STEM education (Education Council, 2015, p.11; OCS, 2014, p. 7; QCAA, 2019, p.1). T1 suggests that problem solving is a key characteristic of the PCC enactment strategy, as

> [b]y exposing them to these problems and allowing them to come up with their own solutions and… their own problems, we're changing the way that they think, and then they can apply that across all spectrums. Whether it's another subject, whether it's when they go home, out into the community. As you're changing their brain, they take their brain with them everywhere. (p. 9)

Inevitably in an open-ended problem-solving environment there are many tangents that can be followed and there may be instances where students are distracted by details unrelated to the problem they have framed. T1 reflects that this is an important part of the learning experience in the STEM Studies classroom, suggesting that teachers will "let them get off track sometimes as well, because that's a good thing to learn. There is an experience in there as well" (p. 6). However, Fraser et al. (2019) suggest that there is a need for data to show the effects of a transdisciplinary learning model on student learning, a sentiment that became particularly important when consider students who feel disengaged in the PCC STEM Studies classroom.

Teaching staff identified the need to work relationally with students who may display disengaged behaviours in the classroom. Strategies used when working with students who aren't comfortable in the open-ended environment included working relationally and providing extra scaffolding. T1 reflects that:

> I feel that those students, they like structure… we have to change our approach a little bit and just work a lot closer with them. Maybe giving them a little bit more guidance, a little bit more scaffolding, and slowly ease them towards the… open-endedness. (p. 7)

Scaffolding the process and helping students create structure within their projects can be key to re-engaging students who are feeling uncomfortable, as described by T1, "… give them a bit of scaffolding around feeling secure so that they think, "Oh, actually I have got a bit of structure, it's not as bad as I thought." As they get more and more comfortable, we can take away [the scaffolding]." (p. 8).

Questioning techniques were identified as an important classroom tactic for engaging a problem-solving mindset with students. T1 suggests a list of questions that they frequently utilise when discussing projects, roadblocks or tangents with students, such as "What's it like? Where's everyone at? Are you understanding? Are you on track? Have you deviated by far? Do I need to intervene a bit more, or do I need to give you a little bit more freedom?" (T1, p. 6).

The final pedagogical technique identified within the PCC enactment strategy, was intentional and explicit learning activities that develop students' interpersonal skills by developing understandings of self, teams and society. T1 reflects on the use of personality testing with students for the purpose of making teams of complementary working styles, saying

> …one of the things we did… was expose them to… MBTI. And we talked about working in groups and solving problems in teams. And having those different skills of people that you need to solve problems. That you might need to engage with different people sometimes. We…try and get them to think about… maybe don't always go with your friends. (p. 10)

Summary of Secondary Coding Domain: Goal-oriented behaviours, acts or activities

The goal of designing a timetabled STEM subject for Years 9 and 10 students and having it approved for implementation was met by the actions of administration and teaching staff identifying space within the secondary timetable and a clear, agreed upon purpose of the subject. Through the early years of enactment, the types of problems that students addressed within the subject became increasingly authentic and meaningful through a negotiation process and by arriving at a shared definition of the term "real-world" problem. The PCC enactment strategy may be considered as leading change in STEM curriculum enactment, as this case study provides data that describes a transdisciplinary models of STEM education, an approach that was not well described in existing literature in the Queensland context.

The PCC STEM Studies subject emphasises overarching pedagogical techniques such as a responsive pedagogy, questioning and interpersonal skills, rather than discrete technology-based activities which were prevalent in case studies examined in the literature.

5.3.2 Secondary Coding Domain: Emotion-oriented behaviours, acts or activities

The results in this section examine results in the secondary coding domain of emotion-oriented behaviours, acts and activities, for both the autoethnography and semi-structured interview data. Emotion-oriented behaviours, acts and activities describe actions taken by actors within the enactment strategy, for emotionally driven purposes. Within this case study the actions that were emotionally driven include the beginning conceptualisation of the project, student responses to the challenges of working in a classroom that is different from their other classes, and concerns about future iterations of the STEM Studies subject. Consideration of emotion-oriented actions is important in this case study to ensure that contextual responses can be separated from transferable principles of enactment. Excerpts of primary data are listed below in Table 12 (autoethnographic data), Table 13 (semi-structure interview data: administration perspective) and Table 14 (semi-structured interview data: teaching staff perspective). The emotion-oriented actions are then described below, in chronological order of enactment phase.

Table 12.

Autoethnographic data: emotion-oriented behaviours, acts or activities

Tertiary code	Quotes
Watchful	"When I considered some of the projects that people were presenting as STEM (E.g., the UQ Sunflower growing competition), I wondered "Where's the Maths in that?" (Entry A, 2021) "We discussed why STEM is important, and that it's a clear national priority and policy directive, without curriculum guidance for schools. We discussed a revamp and expansion of the current STEM program - into earlier years of high school" (Entry H, 2021) "Sometimes the students feel frustrated with the process" (Entry N, 2021) "…they are still coming into the elective subject with closed mindsets and wanting teacher guidance." "…the 10 STEM students still seem very limited in their thinking - even though the majority of them have been through the 9 STEM program. The 9 STEM program seems to be a bit too disjointed, without a resolution or flow to the discrete projects they have been completing" (Entry K, 2021) "they haven't yet developed the ability to release their minds to dream bigger. It still felt like they were trying to produce work that would please the teacher, rather than creatively reacting to problems" (Entry K, 2021) "It's incredible to see them finally enacting all the teaming, interpersonal intelligence, clear communication, support for others and iterative innovation that we have been working them towards throughout the year" (Entry M, 2021)
Worrying	"feeling really intimidated by everyone telling me how important STEM is." (Entry A, 2021) "I left that 2015 conference with a strong sense of guilt that we weren't doing STEM at our school" (Entry A, 2021) "[Administration staff are] starting to realise the importance of STEM education, and [feel] the guilt of inaction when confronted with policy imperatives" (Entry H, 2021)

Table 13.

*Semi-structured interview data: **a**dministration perspective of emotion-oriented behaviours, acts or activities*

Tertiary code	Quotes
Watchful	"If we're not training up students to actually deal with [complex problems] and walk in that space, then we've actually done the next generation a disservice" (A2, p. 7) "…for the current team, I think what's been really important has been the unity of purpose and staying pure to what it is, or evolving together in our thinking as we keep learning and growing in our understanding" (A1, p. 6) "… the future of our work is looking like it's going to be more around those [problem framing and solving] skills rather than being an expert in a particular area, though of course both are needed" (A1, p. 9)

Table 14.

*Semi-structured interview data: **t**eaching staff perspective of emotion-oriented behaviours, acts or activities*

Tertiary code	Quotes
Complaining	"…they can get quite frustrated as well, and some of them have expressed that, that they're not happy" (T1, p. 8)
Watchful	"Some of them really embrace it and they do really well. Whereas others, it's not as much their cup of tea, so they won't engage to the same extent" (T1, p. 5) There has been "… change towards self-improvement… and becoming more proactive, …asking for feedback, …[and] taking on advice as well" (T1, p. 10) and students are "less afraid to not always have it right… [they're] happy to be able to accept that this is good enough for now… to keep moving forward and improving" (T1, p. 10 but said by TD, to which T1 responded "Yeah."). "… it's a little bit hard for students to sometimes break their habits of, "I'm at school, I'm in a class, so I don't do anything" … it's nice to have a little subject [where] they're allowed… to do something different, …have a little bit of fun and then talk about what they did." (T2, p. 10) "it's always about continuous improvement… eventually seeing it… spreading more throughout the school." (T1, p. 11) "I think what's more important, especially [in] this pandemic era that we've been living through, is the ability to plan and adapt... It's far more serious to teach our students those skills, to plan and adapt, change, innovate and keep on going forward to reach a goal" (T2, p. 11)

Reflecting on the pre-enactment phase, the actors of the STEM curriculum innovation at PCC displayed emotion-oriented actions. Emotive words pertaining to as guilt and worry were used to describe how participants felt about their own inaction before enactment occurred, and the confusion over the definition of STEM. Autoethnographical data reflects that “When I considered some of the projects that people were presenting as STEM (E.g., the UQ Sunflower growing competition), I wondered "Where's the Maths in that?" (Entry A, 2021). When considering the current state of STEM education in the Queensland context, autoethnographical data describes “feeling really intimidated by everyone telling me how important STEM is” (Entry A, 2021), and “I left that 2015 conference with a strong sense of guilt that we weren't doing STEM at our school” (Entry A, 2021). From an administration staff perspective, PCC are aware of policy imperatives such as workforces of the future but use emotive language when describing student outcomes: “If we’re not training up students to actually deal with [complex problems] and walk in that space, then we’ve actually done the next generation a disservice” (A2, p. 7). The pre-enactment phase can be characterised as the emotional driver for action towards implementation of STEM education at PCC.

The emotional investment of teachers leading to action in curriculum innovation is not a novel idea. One longitudinal study conducted with Canadian Mathematics teachers enacting innovative curriculum in response to policy (Sheikh & Bagley, 2018) points to emotional investment as an important component of policy enactment. Sheikh and Bagley (2018) describe emotional investment as teachers “caring for their jobs and in particular the students whom they taught” (p. 50), a definition that draws parallels to the emotional language used by teachers at PCC to describe both the STEM course itself and the outcomes for students. Sheikh and Bagley (2018) further suggest that “any aspects of policy enactment which appeared to challenge [traditional educational processes] were scrutinized in terms of attention to student care” (p. 51). This is evident when considering the future of the STEM curriculum innovation at PCC as administration and teaching staff consider their emotional responses to policy. Emotive language used by staff suggests that without learning experiences such as those provided within the STEM Studies subject, students are missing important aspects of an Australian education.

Within the recent enactment phase, emotion-oriented actions can be clearly identified in descriptions of the students' behaviours as they learned to function in a classroom that felt significantly different to others. Students were described as feeling frustrated in some circumstances and empowered in others. T1 reflects on student attitudes towards an open-ended problem-solving process, suggesting "[s]ome of them really embrace it and they do really well. Whereas others, it's not as much their cup of tea, so they won't engage to the same extent" (p. 5). A1 presents an alternate perspective of students emotionally driven behaviours, suggesting that even outside the STEM Studies classroom, they display a "… change towards self-improvement… and becoming more proactive, …asking for feedback, …[and] taking on advice as well" (A2, p. 10). Students are "less afraid to not always have it right… [they're] happy to be able to accept that this is good enough for now… to keep moving forward and improving" (T1, p. 10). T2 suggests that:

> … it's a little bit hard for students to sometimes break their habits of, "I'm at school, I'm in a class, so I don't do anything" … it's nice to have a little subject [where] they're allowed… to do something different, …have a little bit of fun and then talk about what they did. (p. 10)

Students' behaviours within the STEM Studies classroom can have emotional drivers. Throughout the learning process, students experienced frustrations with the difficulty of open-ended problem-solving, however, teachers perceived emotional growth and self-improvement in the students.

In the recent enactment phase, emotion-oriented behaviours are evident in both administration and teaching staff. Administration staff, after evaluation of the STEM curriculum innovation, reported feeling the emotional burden of the policy language and agree with teaching staff that future visions of STEM Studies at PCC will include more student cohorts. Autoethnographical data reflects on a conversation with administration staff, suggesting that "A1 is starting to realise the importance of STEM education, and feels the guilt of inaction when confronted with policy imperatives" (Entry H, 2021). Administration staff are most immediately concerned with the STEM futures purpose of STEM policy language, stating that "… if we're not training up students to actually deal with [complex problems] and walk in that space, then we've actually done the next generation a disservice" (A2, p. 7). Teaching staff echo this sentiment; T1 suggests that “it’s always about continuous improvement… eventually seeing it… spreading more throughout the school.” (p. 11). T2 further reiterates this, by suggesting

> I think what’s more important, especially [in] this pandemic era that we’ve been living through, is the ability to plan and adapt... It’s far more serious to teach our students those skills, to plan and adapt, change, innovate and keep on going forward to reach a goal. (p. 11)

Together, teaching and administration staff feel watchful. They feel the need to monitor and adjust teaching programs to ensure the futures of the students.

Summary of Secondary Coding Domain: Emotion-oriented behaviours, acts or activities

Staff and students involved with the enactment of STEM education at PCC have displayed emotionally driven actions that may impact on the transferable principles of the case study. Conceptualisation of the STEM enactment strategy at PCC can be traced to emotional responses to policy imperatives, which may or may not be present in other settings. In addition, student responses to the challenges of working in a classroom different from their other classes resulted in both negative and positive emotions. Throughout the learning process, students experienced frustrations with the difficulty of open-ended problem-solving, however the growth in students’ problem-solving and lateral thinking skills were described positively by their community. Concerns about future iterations of the STEM Studies subject demonstrate the emotional burden of policy language on the emotional wellbeing of the administration staff as they sought to widen the impact of the STEM Studies program at PCC.

5.3.3 Overall Summary: Primary Coding Domain: Specific Behaviours, Acts or Activities in Enacting the STEM curriculum innovation at PCC

Enacting the STEM curriculum innovation at PCC was initially driven, and continues to evolve, through goal-oriented and emotion-oriented behaviours, acts and activities. Reflecting on the enactment phases, there were occasions that teaching staff and administration staff identified similar behaviours, acts or actions that were imperative in developing, enacting and reviewing STEM Studies at PCC, such as the pedagogical techniques employed in the classroom, and the emotional drivers that spurred action. Conceptualisation of the STEM enactment strategy at PCC can be traced to emotional responses and feelings of guilt regarding policy imperatives, producing actions thereafter that allowed actors to meet goals of enactment. Designing a curriculum time STEM subject for Years 9 and 10 students and having it approved for implementation required clear goal-oriented actions from both administration and teaching staff to develop, resource and timetable a new subject within curriculum time. Within the classroom, emotion-oriented behaviours are clearly identified within the student population, where actions such as disengagement can be seen when they experience challenge and frustrations. Both teaching and administrative staff demonstrated an emotional investment in the curriculum innovation and scrutinised the enactment strategy with attention to student care. The PCC enactment strategy emphasises transdisciplinary pedagogical techniques such as a responsive pedagogy, instead of discrete technology-based or subject-specific activities. Looking to the future of enactment, concerns about future iterations of the STEM Studies subject were raised, that demonstrate the emotional burden of policy language as PCC staff sought to widen the impact of the STEM Studies program on the broader PCC school community.

Now, analysis turns to the second Primary Coding Domain focused on rules, structures, constraints and ideologies.

5.4 Results of Primary Coding Domain: Rules, structures, constraints, ideologies surrounding STEM curriculum implementation at the study site

This primary coding domain aims to exemplify the rules, structures, constraints and ideologies that provided the foundation for the case study's enactment strategy. Analysis of the autoethnography and semi-structured interview data is listed in sections below, by secondary coding domains. Within each section, excerpts of primary data related to the secondary domain being discussed are presented in tables: extracts of autoethnography data and extracts of semi-structured interview data. Analysis is then organised by chronological enactment phases, to demonstrate the range of behaviours, acts and activities that have been identified at each developmental stage of this case. Not all enactment phases are discussed in relation to each secondary coding domain; only those phases that were co-located in the data.

5.4.1 Secondary Coding Domain: Rules

The results in this section examine results in the secondary coding domain of rules, for both the autoethnography and semi-structured interview data. For the purpose of this study, “Rules” as a coding domain has been defined as documented rules that define and limit the operationalisation of resources that relate to timetabling, curriculum and pedagogy, the purpose of the curriculum, the purpose of education and the purpose of STEM education. For example, QCAA provide time allocation rules regarding the number of hours students should be allocated within a school’s timetable per subject (QCAA, 2011). Exclusion criteria for this included enabling structural features of the case study, for example how the school decided to structure the timetable, curriculum and pedagogy.

Throughout the review process, there were no clear occurrences of rules identified in any of the data sources. This is an important gap in the current understanding of how STEM education is conceptualised, the underpinning policy and contemporary enactment advice. In many ways, this silence in the language speaks to the murkiness that surrounds the definition and purpose of STEM education and the lack of clear implementation advice that is available. Poignantly, it may also explicate the absence of curriculum documentation, in the current Australian climate of prescriptive curriculum documentation. ACARA (2018c) state that the structure of the Foundation – 10 Australian Curriculum is “presented as a progression of learning… that makes clear to teachers, parents, students and others in the wider community what is to be taught, and the quality of learning expected of young people” (p.1). Without a STEM curriculum, it follows that rules that define and limit enactment will also be absent.

5.4.2 Secondary Coding Domain: Structures

The results in this section examine results in the secondary coding domain of structures, for both the autoethnography and semi-structured interview data. The “Structures” coding domain describes the considerations and enablers of the STEM

Studies course at the case study site, including timetabling, resourcing, curriculum and pedagogy and how these things scaffold the perceived purpose of STEM education. Curriculum and pedagogy featured heavily within this coding domain, as many of the participants provided detailed descriptions of how the STEM Studies course has evolved over the enactment period. Excerpts of primary data are listed below in Table 15 (autoethnographic data), Table 16 (semi-structure interview data: administration perspective) and Table 17 (semi-structured interview data: teaching staff perspective). The structures are then discussed below, in chronological order of enactment phase.

Table 15.

*Autoethnographic data***:** *structures*

Tertiary code	Quotes
Curriculum & pedagogy	"…we wanted to give them the freedom to respond to problems in authentic, meaningful and tangible ways, without the restrictions of "what would my teacher want me to write"". (Entry C, 2021) "This was a really valuable learning experience as it allowed us to refine how to speak to students about what they should do, what to place emphasis on and how to complete a task, when there wasn't clear criteria (as there often isn't in life)" (Entry C, 2021) "Assessment at this stage was made up of self-reflection tools used at a number of times throughout the year - sometimes it took the form of student conferences (presenting to the class in exchange for feedback) or one-to-one interviews with the teaching panel" "… we did not provide an A-E grade. There was a comment associated with the class, however, that had an explanation of why there was no A-E grade." (Entry C, 2021) "…the decision was made that we needed to provide an A-E grade for students. This was for 2 main reasons: the leadership team decided that there needed to be an A-E grade for every subject. Secondly, there was discussion in the wider cohort that STEM was a "bludge" subject, as you didn't have to do any work." (Entry C, 2021) "… students were not feeling rewarded for the hard work they were doing. The students in the class knew it was not a bludge" (Entry C, 2021) **"**The next problem we faced was how to come up with the A-E grade. We toyed with a few different [ideas]… [however] we settled on creating a rubric associated with the 21st century skills (QCAA, 2019)." (Entry C, 2021). "The concept was that it was going to be like a professional development conference - students would be delegates who attended, learned, were served professional food, and given opportunities to network with speakers and other students." (Entry L, 2021)

	“One key process that we feel has provided some key learning experiences in the Year 10 program, is the concept of creating cognitive dissonances.” (Entry L, 2021) “For example… we intentionally giving them the wrong resources to respond to the problem. The intention is that they learn very quickly, through the process of asking for / wishing for something else, that choosing the right tool / resource for the task is really important in moving a project ahead…. [Or] we give them a very limited amount of time to complete a project. We ask too much of them within a short time period. The idea being, that they learn the process of planning and time management through the experience of working under extreme time constraints.” (Entry L, 2021) “…it is important to ensure the first instance of cognitive dissonance that we create for the students to experience has a short working time, and they find out the "secret" that we (e.g.) gave them the wrong resources to solve the problem quickly.” (Entry N, 2021) “The feelings of frustration are an important part of the experience, but finding the balance between learning through emotive experience and giving up due to frustration is really important. If it goes on too long, they will feel disheartened and even angry. The time that you allow the experience to happen can be extended as they learn that it is a teaching tool, but the first one must be short and sharp.” (Entry N, 2021) “…the year 9 program… has become too segmented and doesn't flow nicely into the year 10 program. Need to infuse more explicit teaching of the thinking skills. maybe make smaller chunked projects interspaced with other activities” (Entry G, 2021) “…the 10 STEM students still seem very limited in their thinking - even though the majority of them have been through the 9 STEM program. The 9 STEM program seems to be a bit too disjointed, without a resolution or flow to the discrete projects they have been completing” (Entry K, 2021) “We decided to move the ‘Turtlegate intro to STEM’, traditionally done at the beginning of Year 10, to Term 4 of Year 9. Not sure at this stage what we will move into Term of Year 10 - but perhaps some reflection with the current cohort as to what they think they are missing from the program” (Entry K, 2021) “Students need to be able to design their own learning from the viewpoint of organically seeking the skills, knowledge and expertise that is contextually needed at that point in time” (Entry T, 2021) “It's no wonder they [the students] find the STEM way of working hard to adjust to, when it's so different from their normal. I think that's why it's been really important to explicitly name Term 4 in Year 9 STEM "Unlearning how to learn". We have explicitly told the students that we don't want them to operate in the same way as their other classes. They need to unlearn their habits - particularly the habit of responding in ways that please the teacher. We are not looking for the answers in our heads - we want the answers from yours!” (Entry U, 2021)

Table 16.

Semi-structured interview data: administration perspective of structures

Tertiary code	Quotes
Timetabling & resources	"We were in a good place to take a risk on a room". (A2, p. 5) "… at a very pragmatic level, it fills a gap" (A2, p. 6) "… resourcing hasn't been an issue for us… [it's] been really helpful, not having to create a whole STEM lab before we could even start… we've been able to work with what we have" (A1, p. 11) "By having it as a part of our curriculum, [students have] a whole year of focus time" (A1, p. 4). "… they can really take on that transdisciplinary approach and go beyond… an add-on" (A1, p. 4)
Curriculum & pedagogy	"collaboration, the problem-solving approach, good questions of inquiry… and practical… [and] student agency… which goes hand in hand with that inquiry" (A2, p. 4) "the design process has been used a lot… it's very much problem-based… and elements of inquiry… the students having freedom to guide where they go instead of having a set of curriculum content" (A1, p. 5) A1 describes the program as "student-centred", "meeting the students where they're at, and allowing them to direct their learning" and "collaborative" (A1, p. 5) "STEM conference was awesome" (A1, p. 12)
Purpose of STEM education	"We went on our own journey of understanding… about what STEM is, and what it might look like at Parklands" (A2, p.2) "If it's just about problem-solving, then in a sense you kind of have to give them the problem…. For them to just focus on the solution part of it. Whereas, if we actually want the students to choose something that's meaningful to them that they're passionate about, then they need those skills to be able to… frame it so that they can move onto the solution" (A1, p. 6)

Table 17.

Semi-structured interview data: teaching staff perspective of structures

Tertiary code	Quotes
Curriculum & pedagogy	In Year 9, the course is about “exposing them to STEM… and getting them building some skills that they can use. By doing lots of smaller projects, building up skills… we can [then, in Year 10] expand that out and do some bigger projects and come up with their own problems” (T1, p. 3) “very open-ended and multiple entry and exit points… because different kids and different” (T1, p. 5) “… set a task that is very difficult for the student and they’re meant to struggle with it… in order to learn along the way. It’s very collaboratively and… we encourage self-efficacy… in order for the students to reflect on how they’re going and reflect on their own work and if they’re reaching their goals. (T2, p. 5) “… student-focused… or student-centred is probably a better word. Or student-driven maybe” (T1, p. 4) “…student-centred, project-based learning” (T2, p. 5)
Purpose of STEM education	“Problem solving is one of the main ones… [and] understanding a problem or a situation. Being able to interpret it, break it apart, and see what are the various… aspects that are involved with this problem? And then what do they actually need, or how do they address it? Once they’ve done that they can then start to tackle, okay, how do we address this problem? So, what resources do I need? What knowledge do I need? What sort of people would I need?... How do I engage those people? How do I communicate? And… then present their solution” (T1, p. 3) “… allowing students to learn how to problem solve, which is something that then they can take to other subjects further down the track into life and so on, like these skills that overlap all these different industries that allow them to be exposed to a range of problems in order for them to adapt to the future and adapt to changes.” (T2, p. 8).

Enabling structures that were established during the pre-enactment phase were focussed on timetabling and structures. PCC staff recognised that there being space in the subject lines for a Year 10 subject and resources that suited the curriculum design of the subject. These structures were a pre-existing resource at this site which enabled the STEM curriculum innovation to be realised. At PCC, the STEM Studies subject was initially approved to be enacted in curriculum time, because “[w]e were in a good place to take a risk on a room” (A2, p. 5), and “… at a very pragmatic level, it fills a gap” (A2, p. 6). At PCC, STEM is set up as a part of the curriculum timetable, for the purpose of moving beyond superficial enactment of the STEM Education policy directives. “By having it has a part of our curriculum, [students have] a whole year of focus time" (A1, p. 4), and "…they can really take on that transdisciplinary approach and go beyond an add-on" (A1, p. 4). Resourcing beyond timetabling and learning spaces were also not an initial consideration in approving the STEM Studies subject, due to the nature of the course that was designed. As stated by A1 (p. 11), "… resourcing hasn't been an issue for us… [it's] been really helpful, not having to create a whole STEM lab before we could even start… we've been able to work with what we have". Throughout the pre-enactment phase of STEM curriculum innovation at PCC, timetabling and resources were not significant barriers in the initial development and approval of the subject because the program utilised pre-existing resources. Curriculum and pedagogical structures, however, were structures that made the enactment of STEM Studies more challenging.

In the recent enactment phase innovative curriculum and pedagogical structures were identified as the enabling factors that facilitated enactment of STEM education at PCC. Across the autoethnography and interview data, groups of participants listed curriculum and pedagogical structures that they believe are foundational to making the STEM Studies subject work. Table 18 below shows the structures that each group of participants valued, with similarities noted when reading across rows.

Table 18.

Curriculum structures utilised in STEM Studies at PCC

Curriculum structure	Autoethnography data	Administration Staff	Teaching Staff
Collaborative approach	Teamwork focus and fluid groupwork	Collaboration	
Problem-solving approach	Problem-framing approach	Problem-solving approach	Problem-focussed
Inquiry-based approach		Questions of inquiry	Open-ended inquiry
Real-world approach		Practical approach	
Student-led approach	Non-traditional assessment items that are student-centred	Student agency	Student-centred approach
School-based curriculum		Absence of published curriculum content	
Experiential learning approach	Cognitive dissonance opportunities		Cognitive dissonance opportunities
Connections beyond the classroom	STEM conference	STEM conference	

The administrative staff described the pedagogical framework employed in the STEM Studies subject as student-centred, with elements of a problem-solving and inquiry-based approach. A1 describes the program as “student-centred, meeting the students where they’re at, and allowing them to direct their learning” (p. 5), and A2 describes the program as one that utilises “collaboration, the problem-solving approach, good questions of inquiry… [and] student agency… which goes hand in hand with that inquiry” (p. 4). Administration staff also compared the STEM Studies subject enacted at the case study site with other enactments of STEM education they had witnessed at other locations. “… broadly across Queensland, STEM would be focused on the discrete subjects, the science, the maths and the technologies particularly”, and suggesting STEM is “often with a technology component, the drones and robots… seem to have the focus” (A1, p. 2). Teaching staff described the structure of the STEM curriculum innovation and enactment strategy utilised at PCC very clearly. The four key structures described were a problem-focused curriculum, cognitive dissonance learning opportunities, an open-ended approach to learning and project work as well as a student-led program. The Year 9 program is described as “exposing them to STEM… and getting them building some skills that they can use. By doing lots of smaller projects, building up skills… we can [then, in Year 10] expand that out and do some bigger projects and come up with their own problems" (T1, p. 3). T1 further describes the approach to teaching and learning as "very open-ended and multiple entry and exit points… because different kids are different" (p. 5). Cognitive dissonance learning experiences are an important facet of the program, as described by T2. In these types of activities, which can occur within a single lesson or across a term of learning, teachers

… set a task that is very difficult for the student and they're meant to struggle with it… in order to learn along the way. It's very collaborative and… we encourage self-efficacy… in order for the students to reflect on how they're going and reflect on their own work and if they're reaching their goals. (T2, p. 5).

In essence, staff at PCC suggest that learning through experiential difficulties encourages resilience, self-efficacy and collaboration, is a helpful pedagogical tool within a student-led, problem-focussed curriculum. PCC's student-centred, problem-focussed STEM Studies curriculum utilises general capabilities such as collaboration and understanding of self and others. This approach to curriculum aligns with policy imperatives for STEM education in Australia. For instance, student agency through inquiry learning (DESE, 2020b; DET, 2020), problem solving (ACARA, 2016; OCS, 2014) and 21st century learning or general capabilities (DESE, 2020b; DET, 2020) are features of STEM education described across the assemblage of policy. Data gathered from teachers and administration staff highlight the synergies of PCC STEM Studies with these policy imperatives.

In curriculum studies, assessment is a significant structure that drives teaching and learning. In the first and second year of enactment of the STEM Studies program, determining an assessment strategy was the focus of many curriculum decisions, as "…we wanted to give them the freedom to respond to problems in authentic, meaningful and tangible ways, without the restrictions of "what would my teacher want me to write" (Entry C, 2021). Without clear implementation advice for how to enact a STEM program, the PCC curriculum innovation aimed to link pedagogical and assessment structures back to the policy described purpose of STEM education, that is, preparing students for workplaces of the future (Education Council, 2015; Queensland Curriculum and Assessment Authority, 2017). As such, the focus of the curriculum turned to factors of project management that facilitated problem-solving, and how teachers interact with the students throughout this process.

> This was a really valuable learning experience as it allowed us to refine how to speak to students about what they should do, what to place emphasis on and how to complete a task, when there wasn't clear criteria (as there often isn't in life). (Entry C, 2021)

Assessment throughout this process consisted of "… self-reflection tools used at a number of times throughout the year - sometimes it took the form of student conferences (presenting to the class in exchange for feedback) or one-to-one interviews with the teaching panel". Whilst in the earliest enactment phase the plan was to not provide an A-E grade for the subject to release students from the pressure of external expectations, "… students were not feeling rewarded for the hard work they were doing" (Entry C, 2021), and therefore "[t]he next problem we faced was how to come up with the A-E grade. We toyed with a few different [ideas]… [however] we settled on creating a rubric associated with the [QCAA, 2019] 21st Century skills" (Entry C, 2021). The original marking scheme developed at PCC used QCAA's (2019) 21st Century skills of critical thinking, creative thinking, communication, collaboration and teamwork, personal and social skills; and ICT skills as criteria. The criteria were presented in a matrix using words of discernible difference across a 5-point scale. These rubrics were used to make judgements about student work, and also for students to complete self-assessments.

With a lack of clear implementation advice in policy documentation, pedagogical structures utilised within the PCC curriculum innovation during the middle enactment phase (Years 2-3) also endeavoured to reflect policy language. 21st Century learning and preparing students for unknown futures (Education Council, 2018; Education Council, 2019a; Education Council, 2019; OCS, 2013, 2014). For instance, a teacher links unknown futures with the use of cognitive dissonance: "[o]ne key process that we feel has provided some key learning experiences in the Year 10 program, is the concept of creating cognitive dissonances" (Entry L, 2021). Autoethnography data further suggests that:

> For example… we intentionally [give] them the wrong resources to respond to the problem. The intention is that they learn very quickly, through the process of asking for / wishing for something else, that choosing the right tool / resource for the task is really important in moving a project ahead…. [Or] we give them a very limited amount of time to complete a project. We ask too much of them within a short time period. The idea being, that they learn the process of planning and time management through the experience of working under extreme time constraints. (Entry L, 2021)

This process must be delicately balanced, as students can feel frustrated by the process. Therefore,

> …it is important to ensure the first instance of cognitive dissonance that we create for the students to experience has a short working time, and they find out the "secret" that we gave them the wrong resources to solve the problem quickly. (Entry N, 2021)

because,

> The feelings of frustration are an important part of the experience, but finding the balance between learning through emotive experience and giving up due to frustration is really important. If it goes on too long they will feel disheartened and even angry. The time that you allow the experience to happen can be extended as they learn that it is a teaching tool, but the first one must be short and sharp. (Entry N, 2021)

Cognitive dissonance learning experiences remain as a pedagogical structure within STEM Studies at PCC. This strategy is implemented purposefully and thoughtfully to ensure students are able to learn effectively through the process, and to enact policy language of being prepared for unknown futures (OCS, 2013, 2014).

When reflecting on the most recent enactment phases, autoethnographical data suggests that there has been a shift in focus to the Year 9 program. Throughout the recent enactment phase, autoethnographical data reflects that "…the [Y]ear 9 program… has become too segmented and doesn't flow nicely into the [Y]ear 10 program. Need to infuse more explicit teaching of the thinking skills. maybe make smaller chunked projects interspaced with other activities" (Entry G, 2021). This sentiment seems to align with the observations of STEM education in Queensland that is generally focussed on activities or extra-curricular clubs with a focus on digital technologies rather than on thinking skills (Chaiwongsa, Kinboon & Yanasarn, 2019; VanMeter-Adams, Frankenfeld, Bases, Espina & Liotta, 2015). The thinking skills that seemed to be missing from the students' performance in the STEM Studies subject was described by autoethnographical data as "…organically seeking the skills, knowledge and expertise that is contextually needed at that point in time" (Entry T, 2021). Subject specific knowledge, understanding and skills have an important place within discipline-based learning (OCS, 2013, 2014). However, without the enactment of STEM education, opportunities for students to apply these learnings in different contexts is limited. The PCC curriculum innovation would suggest that the contextual application of knowledge and skills in an integrated learning environment are important experiences, because students are challenged to think and create in different ways. Autoethnographical data reflects on PCC students' mindsets when engaged with STEM Studies, saying

> It's no wonder they [the students] find the STEM way of working hard to adjust to, when it's so different from their normal. I think that's why it's been really important to explicitly name Term 4 in Year 9 STEM "Unlearning how to learn". We have explicitly told the students that we don't want them to operate in the same way as their other classes. They need to unlearn their habits - particularly the habit of responding in ways that please the teacher. We are not looking for the answers in our heads - we want the answers from yours! (Entry U, 2021)

When policy documentation describes STEM education as integrated or with strong foundations in problem-solving (Department of Education, Skills & Employment, 2019; Education Council, 2015, 2019; OCS, 2013, 2014), the purpose of teaching in this way is to educate young Australians into an unknown future and to develop the skills to be successful in unknown workforces and tackle complex problems (Education Council, 2018; Education Council, 2019a; Education Council, 2019; OCS, 2013, 2014). This priority is described as core to the PCC enactment strategy, as expressed by T2 who suggests that

> … allowing students to learn how to problem solve, which is something that then they can take to other subjects further down the track into life and so on,

> like these skills that overlap all these different industries that allow them to be exposed to a range of problems in order for them to adapt to the future and adapt to changes. (p. 8)

However, at PCC, the administration and teaching staff have both identified through enactment experience that problem-framing is an important structure that is imperative to the success of the STEM Studies subject. As observed by A2, “We went on our own journey of understanding… about what STEM is, and what it might look like at Parklands” (p. 2). A1 further commented that

> If it’s just about problem-solving, then in a sense you kind of have to give them the problem…. For them to just focus on the solution part of it. Whereas, if we actually want the students to choose something that’s meaningful to them that they’re passionate about, then they need those skills to be able to… frame it so that they can move onto the solution. (p. 6)

Problem-framing is not clearly mentioned in policy imperatives or implementation advice, unlike problem-solving, which is explicitly stated (ACARA, 2016a; DESE, 2016; DET, 2017; Education Council, 2015, 2019; Lowrie, Downes & Leonard, 2017; OCS, 2013, 2014; QCAA, 2017; Rosicka, 2016). Through Years 2 and 3 of STEM curriculum enactment at PCC, teaching staff observed that students were feeling frustrated with the problem-solving process, and it was hypothesised that it was due to students’ lack of problem-framing skills. T1 suggests that an important aspect of the STEM Studies curriculum throughout the recent enactment phase is

> … understanding a problem or a situation. Being able to interpret it, break it apart, and see what are the various… aspects that are involved with this problem? And then what do they actually need, or how do they address it? Once they’ve done that they can then start to tackle, okay, how do we address this problem? So, what resources do I need? What knowledge do I need? What sort of people would I need?... How do I engage those people? How do I communicate? And… then present their solution. (p. 3)

Summary of Secondary Coding Domain: Structures

Timetabling and resources were not a barrier in the initial approval of the PCC STEM subject as there was circumstantial space in the timetable and curriculum design did not privilege traditional models of technology-focussed activities. Instead, curriculum decisions focused on assessment strategies, cognitive dissonance experiential learning, problem framing, problem solving and 21st century skills, each based on priorities identified in policy (ACARA, 2016a; DESE, 2016; DESE, 2019; DET, 2017; Education Council, 2015, 2019; Lowrie, Downes & Leonard, 2017; OCS, 2013, 2014; QCAA, 2017; Rosicka, 2016). PCC staff suggest that discrete learning areas subject-specific knowledge, understandings and skills are important components of STEM education. However, working in the integrated space between subjects, where problems usually exist, is a priority in the curriculum innovation, and set out as one of the purposes of STEM education in policy (Department of Education, Skills & Employment, 2019; Education Council, 2015, 2019; OCS, 2013, 2014). Enactment of a transdisciplinary STEM education pedagogy, alongside the development of subject-specific knowledge, understandings and skills, provides opportunities for students to both frame and solve problems that exist between the boundaries of discrete subjects, where they are challenged to think and work in innovative ways.

5.4.3 Secondary Coding Domain: Constraints

The results in this section examine results in the secondary coding domain of constraints, for both the autoethnography and semi-structured interview data. The "Constraints" coding domain describes any constraints that were encountered within the enactment of the STEM Studies course at the case study site, including timetabling, resources, curriculum and pedagogy and how they can influence the perceived purpose of STEM education. Excerpts of primary data are listed below in Table 19 (autoethnographic data), Table 20 (semi-structure interview data: administration perspective) and Table 21 (semi-structured interview data: teaching staff perspective). The structures are then discussed below, in chronological order of enactment phase.

Table 19.

Autoethnographic data: constraints

Tertiary code	Quotes
Timetabling & resources	"There are significant timetabling and mindset in leadership issues that we will face to get this off the ground in primary school." (Entry H, 2021) "[Administrator] raised the thought, what if we started at the youngest end: Prep and Year 1. "Get them before we break them"." (Entry H, 2021) "Three times this year now, I have pitched the transdisciplinary STEM approach, with an expanded program that can even extend to P-10, working within curriculum time. I feel like our Year 9-10 program provides a strong proof of concept, and that it's time for the next evolution / expansion. However yet again I am met with inaction. Their reasoning seems to be most strongly linked to making space in the timetable. There's no time/space to fit this in, therefore it won't happen" (Entry I, 2021) "…We were led to believe that STEM could be implemented with Year 7 and 8 next year, but now find out… that it won't be going ahead due to timetable issues" (Entry Q, 2021) "…two key things in getting a STEM program implemented in curriculum time would be timetabling, but also leadership who are willing to take risks and do the hard work of making room. (Entry Q, 2021)
Curriculum & pedagogy	"…3 out of 4 candidates referenced their experiences in Year 10 STEM as to how they learned to work well with others. [Administrator] described this as "proof of concept" that the STEM course is building soft skills in students, but also that they are reflective enough to be aware of it." (Entry S, 2021)

Table 20.

Semi-structured interview data: administration perspective of constraints

Tertiary code	Quotes
Timetabling & resources	“a… logistical challenge” (A1, p. 9) “… it’s created a lot of good challenge for the executive team as well as the education team” (A1, p. 11)
Curriculum & pedagogy	“STEM has been around as a concept for quite some time, but it depended on who you asked, it would give you very different answers [and] feedback about what STEM was” (A2, p.2) “It’s like, what does STEM mean to you?” (A2, p.2) “…typically you go and see a facility at a school and they say they’ve got STEM, there’s robots and engineering type stuff. That’s about it” (A2, p.3) “a teacher needs to see the opportunity for innovation and collaboration... taking the risk of student agency, because that in itself is risky for a staff member” (A2, p. 4) “… it’s a big risk. And if this goes badly, it’s going to be on me” (A1, p. 9) “I’m the kind of person that goes, “ooh, that sounds new and creative. Let’s pursue that… but if I actually had to do something, that would not excite me” (A2, p. 5) “… budget is a serious consideration. How do we actually pull this off without spending any extra money?” (A2, p. 6) “… projects like these are as good as the staff that you have at the time. Longevity for me is a concern.” (A2, p. 6) When discussing how to expand/evolve the PCC enactment strategy, A1 suggests that “I’m not exactly sure yet what we do with that, but I think it’s something we’re going to have to keep working through if we’re going to bring others into the program” (A1, p. 7) “It would be much easier for schools to stay in the coding club or the cross-disciplinary moments rather than going to the transdisciplinary. It’s a harder challenge” (A1, p. 8) “… if we were trying a club and it didn’t work, you go ‘okay cool, that’s fine.’ We can take those sorts of risks. But a whole year’s worth of education, if it hadn’t gone well, that was a significant risk to take” (A1, p. 10) “I don’t have the specific data… but I would think that from what I’m hearing, they are growing in those areas” (A1, p. 10) “…[teachers] are aware they should be incorporating STEM into their classrooms, but they don’t know how, they’re too busy” (A1, p. 12) “…if we can get in with those littler ones and get them developing the skills earlier on, I think the whole school will benefit from that as well as the students themselves” (A1, p. 12).

Table 21.

Semi-structured interview data: teaching staff perspective of constraints

Tertiary code	Quotes
Curriculum & pedagogy	"I have seen a change with one particular group this year that's really embraced it… they're working a lot better together" (T1, p. 10). "…you come across something that's like, "This is different. Yeah, I'll give that a go." Then six years later you're sitting here going, "Yeah, that was a lot of work."" (T2, p. 7) "How do we make this not just science?... how do we actually make this something different that is its own thing" (T2, p. 8)

Enactment of transdisciplinary STEM is not without challenges, and constraints within the PCC curriculum innovation were evident in data collected about the pre-enactment phase. Two key challenges emerged throughout the information gathering period before the STEM Studies subject was implemented at PCC: managing the risk associated with doing something new and different, and the logistical considerations of moving from a theoretical approach to a practical one. Typically, expectations of a STEM program in a school environment fall to technology-based activities, as outlined by A2 who suggests that "…typically you go and see a facility at a school and they say they've got STEM, there's robots and engineering type stuff. That's about it." (p. 3). To implement a different approach – one that becomes a part of precious curriculum time – has inherent risks.

The risk associated with implementing an innovative approach was felt by both administration staff and teaching staff at PCC, for a range of reasons. Administration staff observed that implementing the transdisciplinary subject is a risky venture in itself, stating "… it's a big risk. And if this goes badly, it's going to be on me" (A1, p. 9). A2 highlighted that a teacher is taking a risk by working in this way, suggesting that "a teacher needs to see the opportunity for innovation and collaboration… taking the risk of student agency, because that in itself is risky for a staff member" (p. 4). The teacher perspective highlighted reservations about the innovative nature of the subject, stating "How do we make this not just Science?... how do we make this something different that is its own thing?" (T2, p. 8). The inherent risk associated with implementing an innovative way of working within curriculum time was an early constraint in the implementation of the transdisciplinary STEM education at PCC.

The logistical considerations of moving from a theoretical understanding of transdisciplinary STEM education was another constraint recognised early in the implementation of STEM Studies subject at PCC. As described by A2, “I’m the kind of person that goes, “ooh, that sounds new and creative. Let’s pursue that” … but if I actually had to do something, that would not excite me” (p. 5). Having staff who are willing to take a risk within their classroom with their pedagogical philosophy and work outside of typical teacher mindsets has been crucial in the PCC enactment strategy. Importantly, PCC had staff who were willing to do this, as observed by T2, who reflects that “… you come across something that’s like, this is different. Yeah, I’ll give that a go. Then six years later you’re sitting here going… that was a lot of work” (p. 7). Within this case study, action-oriented teaching staff have been critical in overcoming constraints associated with moving from theoretical understanding to practical implementation.

Throughout the recent enactment phase, when considering the next iteration of the STEM curriculum innovation at PCC, three key constraints emerged: timetabling and resourcing; an understanding of the purpose of STEM education; and a lack of clear, contextual success criteria at a policy level. Whilst timetabling and resources did not provide significant challenges to approval and initial enactment, future developments may include an expansion of the program to include more classes at different year levels. The initial enactment was approved due to a convenient gap in the timetable, and because it filled a pragmatic need (A2, p. 2), but considering future developments of STEM at PCC, autoenthnographical data suggests that “[t]here are significant timetabling… issues that we will have to get this off the ground in [other year levels]” (Entry H, 2021). Administration staff also recognise this challenge, but due to the perceived success of the program so far, suggest that “… it’s created a lot of good challenge for the executive team as well as the education team” (A1, p. 11). Even though “our Year 9 and 10 program provides a strong proof of concept… reasoning [for not expanding the program] seems to be most strongly linked to making space in the timetable” (Entry I, 2021). Within this case study, timetabling a subject within curriculum time wasn't an initial constraint. However as future iterations of the program are considered, timetabling has become more of a practical challenge.

The purpose of STEM education, and its place within an educational journey can be the source of a second key challenge for schools. Overarching Australian STEM Education policy documentation does seem to have a substantial and altruistic purpose, even without a clear and agreed upon definition of STEM Education. The purpose of STEM education is usually described as one that prepares students for an unknown future, to solve real-world challenges or to become productive workers in Australia's future (Education Council, 2018, p. 3; Education Council, 2019a, p.15; Education Council, 2019, p. 6; OCS, 2013, p. 3; Office of the Chief Scientist, 2014, p. 7). However, without a clear definition or tangible implementation advice, enactment strategies are highly varied. At PCC, this perspective is clear throughout both administration and teaching staff's perspectives of how STEM education is contextually enacted. "Unfortunately, I think most… schools, when they think of STEM… it's this engineering concept. It's not untrue, but it's not the full picture of STEM" (A2, p. 3). For schools, often a first step for curriculum implementation can be to look at what others around them are currently doing. However, for PCC, it seems that looking at other examples clarified misalignments with the policy described purpose of STEM. "It would be much easier for schools to stay in the coding club or the cross-disciplinary moments, rather than going to the transdisciplinary. It's a harder challenge" (A1, p. 8). PCC further outlines that this harder challenge, of implementing a strategy that is closer in alignment to the policy language of the purpose of STEM is itself not without risk. A1 suggests that

> …if we were trying a club and it didn't work, you go 'okay cool, that's fine', we can take those sorts of risks. But a whole year's worth of education, if it hadn't gone well, that was a significant risk to take. (A1, p. 10)

Aligning an enactment strategy to the policy language can provide significant challenge to schools, however with administration staff that are willing to take a calculated risk, it can be a meaningful experience for students.

A lack of success criteria, or the ability to evaluate a STEM education curriculum innovation, has presented as a constraint within this study. Policy documentation suggests that while evaluative measures, best practice advice and success criteria are central to implementation, they are yet to be developed by authoritative agencies. Watt (2017) suggests that “[a] strong evidence base for STEM should be built by national reports, charging changes in data indicators, and sharing and synthesising research and evaluation” (p. 11). Success criteria are important in the STEM education space, to determine which approaches are the most appropriate for addressing the overarching purposes of STEM education. However, Rosicka’s (2016) review of STEM education describes the current lack of clear success criteria, suggesting that more research is needed, particularly in the integrated STEM education space. At PCC, this lack of clear success criteria in policy language has meant that up until this research, evaluation of the STEM Studies program has been based on anecdotal evidence. T1 mention that they have “…seen a change with one particular group this year that’s really embraced it… they’re working a lot better together” (p. 10). Administration staff recounted a clear example of the impact the STEM Studies program has had on student behaviour, relayed in autoethnographical data saying

> …3 out of 4 candidates [for school captaincy] referenced their experiences in Year 10 STEM as to how they learned to work well with others. A2 described this as “proof of concept” that the STEM course is building soft skills in students, but also that they are reflective enough to be aware of it. (Entry S, 2021)

By describing this evidence as “proof of concept” (Entry S, 2021), it seems that PCC has been using growth in 21st Century skills as an inadvertent success criterion for the students engaged in the course. Whilst the PCC curriculum innovation is beginning to show anecdotal evidence of success within its own context, one aim of this research is to develop transferrable principles of enactment that exemplify policy descriptions of STEM education. This would require evaluative measures, best practice advice and success criteria to be developed by authoritative agencies of which the lack thereof is a current constraint within this study.

Summary of Secondary Coding Domain: Constraints

Within this case study, timetabling was not regarded as constraint in the initial enactment, as there was convenient space within the timetable. Additionally, timetabling was not considered a constraint because leadership recognised that even though risk is inherent in trialling a new pedagogical strategy but were willing move forward because they were presented with a research-based case. This is illustrated by a staff member, who suggests that "… two key things in getting a STEM program implemented in curriculum time would be timetabling, but also leadership who are willing to take risks and do the hard work of making room" (Entry Q, 2021). It is interesting now that when faced with the desire to expand the program, an established proof-of-concept in addition to a research-based case do not outweigh the challenge of finding room within a busy timetable. Aligning an enactment strategy to the altruistic policy language can provide significant challenge to schools, however with administration staff that are willing to take a calculated risk with curriculum time, teacher timetables or resources, it can create meaningful growth in 21st century skills for students. Success criteria for enactment strategies of STEM education is not well defined in policy language. At PCC, assessment is designed to measure growth in students' 21st century skills, however, criteria to evaluate program success from an organisational viewpoint cannot be informed by agreed systemic criteria.

5.4.4 Secondary Coding Domain: Ideologies

The results in this section examine results in the secondary coding domain of ideologies, for both the autoethnography and semi-structured interview data. Within the PCC STEM enactment strategy, the ideological basis from which the curriculum subject was designed can be traced through the enactment phases. Key to this basis is the definition of STEM education as conceptualised by the case study, the foci of each phase of enactment as the program developed, the characterisation of a PCC STEM teacher and the nuanced purpose of STEM within the PCC context. Excerpts of primary data are listed below in Table 22 (autoethnographic data), Table 23 (semi-structured interview data: administration perspective) and Table 24 (semi-structured interview data: teaching staff perspective). Ideologies are then discussed below, in chronological order of enactment phase.

Table 22.

Autoethnographic data: ideologies

Tertiary code	Quotes
Curriculum & pedagogy	"…we were… determined that students would be in charge of marking themselves / deciding what their work was worth - similar to a workplace self-appraisal and then meeting with a team leader." (Entry C, 2021) "The PCC STEM conference idea came from the need for students to widen their perspective of the types of problems they can solve" (Entry E, 2021) "…to find a way to get lots of different professionals from a wide range of industries to speak about their jobs and the types of problems they faced, to inspire students to think bigger. At its conceptualisation, STEM conference was meant to be an idea-generating or inspiration tool." (Entry E, 2021) **"**the point of the Year 9 program is to give many and varied opportunities for skill and knowledge development, as well as soft skill development (trial and error, reiterative process of design)"
Purpose of STEM education	"I didn't really understand what STEM was, except for Science Technology Engineering and Mathematics. I didn't understand how these things could be taught together at the same time, with students effectively learning the depth of knowledge that each of these things bring." (Entry A, 2021) "I knew that I couldn't do it by myself, that I would need the Engineering and Technology knowledge bases to help. So I reached out to T1, my counterpart LT of Design and Technology to see what he thought. I pitched the idea of the subject to him, including a few key thoughts around team teaching, facilitating expert knowledge into the classroom instead of teaching, the key focus on problem-solving and the next step of enacting solutions - not just writing an assignment about what they would do... they actually had to do it" (Entry B, 2021) "An alternate view of the current landscape of STEM education in Australia Lack of refinement in Australian publications is often suggestive of inclusiveness – allowing teachers and schools to take whatever approach they want and still be able to categorise it as STEM education. However, in [recent] curriculum specific events, there seems to be a focus increasing clarity and decreasing confusion. This seems to lead towards more prescriptive boundaries in educational contexts… So with that in mind – for all my discomfort or frustration with the lack of clarity – I probably wouldn't have been able to implement our particular STEM program if I was working with a prescriptive definition." (Entry R, 2021)

Table 23.

Semi-structured interview data: administration perspective of ideologies

Tertiary code	Quotes
Curriculum & pedagogy	"to approach anything in a school from a transdisciplinary approach it not only goes against our training, but the way we form our institutions" (A2, p. 4) "In terms of the skills they need… it's not what comes naturally to teachers… it's actually quite challenging to switch to a different way of thinking" (A1, p. 7) "… it's not necessarily natural to the way teachers work. [Teachers have been] trained to work in ways that are kind of linear in many respects, whereas…. To facilitate this approach, with its intended purpose, it actually requires a teacher to be a much more lateral thinker" (A1, p. 7 but said by interviewer).
Purpose of STEM education	"it's a transdisciplinary approach to a few subjects", "[it] answers a gap in our society in the journey from students to grade 12 and to university as well" (A2, p.2) "It's a promotion of a group of subjects but… it produces something that's truly pragmatic. Something that is tangible and that we can link to beyond school" (A2 p. 3) "I was inspired to think that our students could have a richer learning experience with the presence of a STEM program" (A2, p. 6) "It sounded reasonable enough… but it also sounded inspiring that this could be something that not only changes our school, but possibly could invest in the future of STEM in Queensland and our national curriculum" (A2, p. 6) "I hope that it will give tangible outcomes in terms of helping our kids lead their own learning journey, take risk, value agency and become good critical thinkers outside the creative subjects" (A2, p. 6) "… our world needs creative people… and… that is going to be increasingly so in our future. That we're going to need creative solution to complex problems" (A2, p. 7)

Table 24.

Semi-structured interview data: teaching staff perspective of ideologies

Tertiary code	Quotes
Purpose of STEM education	"… a combination of the various topics that make up the letters… [and]… exploring the application of those subjects." (T1, p. 2) "… it's more around the how do we bring those subjects together to solve problems? And how do we actually use them in real life?" (T1, p. 2) "…trying to address the 21st century thinking skills through engaging tasks that are generally centred around a project or a central problem or like a wicked problem. But, they are generally trying to address… future needs, while teaching the students about how to innovate or think creatively." (T2, p. 2) "… the interconnective nature that you're trying to get in the course is not a namesake, is not just science, technology, engineering, maths." (T2, p. 5) "… it's the thinking skills that we're trying to teach across it. We're not intentionally trying to teach Science, yes we will; we're not intentionally trying to teach Maths, yes we will though, but we're trying to teach… the skills that bend across those things" (T2, p. 6). "it may be based more off art and design curriculum more than it should be and would be less curriculum-focused" (T2, p. 4) "for the students to learn in a rich way what the 21st century thinking skills are, in order for them to be innovative and adapt to a range of curriculum problems or life problems, to allow them to think collaboratively, think of other people's needs, to change their plan along the way, while critically thinking and creatively thinking." "…[we're] providing different experiences, richer experiences" (T1, p. 9) "… the world is changing… I don't know what it's going to look like, but we're going to need people to solve problems." (T1, p. 9)

Throughout the pre-enactment phase, the development of the STEM education curriculum innovation at PCC was born of an ideological journey. The spectrum of discipline-based and cross-discipline STEM education described by policy (ACARA, 2016a; Lowrie, Downes & Leonard, 2017; OCS, 2013, 2014; QCAA, 2017; Rosicka, 2016) was a source of confusion for staff in the earliest stages of development. Reflecting on early encounters with STEM education outside PCC, autoethnographical data states:

> I didn't really understand what STEM was, except for Science, Technology Engineering and Mathematics. I didn't understand how these things could be taught together at the same time, with students effectively learning the depth of knowledge that each of these things bring. (Entry A, 2021)

When considering enacting STEM education at PCC, autoethnographical data then reflects that:

> I knew that I couldn't do it by myself, that I would need the Engineering and Technology knowledge bases to help. So I reached out to T2, my counterpart Lead Teacher of Design and Technology to see what [they] thought. I pitched the idea of the subject to [them], including a few key thoughts around team teaching, facilitating expert knowledge into the classroom instead of 'teaching', the key focus on problem-solving and the next step of enacting solutions – not just writing an assignment about what they would do… they actually had to do it. (Entry B, 2021)

Throughout the pre-enactment phase, PCC formed their ideology of STEM education to align with policy descriptions of problem-solving (ACARA, 2016a; DESE, 2016; DESE, 2019; Education Council, 2015, 2019; Lowrie, Downes & Leonard, 2017; OCS, 2013, 2014; QCAA, 2017; Rosicka, 2016).

In the early enactment phase of the curriculum innovation, PCC focussed the ideological positioning of the program, which focussed on building student agency and training students in non-traditional assessment strategies. Student agency was viewed as an important step away from traditional classrooms, where students are generally producing work that they feel meets a teacher's expectations, rather than creating solutions to problems. As suggested by the Office of the Chief Scientist (2014), "[c]urricula and assessment criteria should prioritise curiosity-driven and problem-based learning of STEM" (p. 21). The curiosity of the students, as young Australians, was valued and explicitly highlighted within both classroom activities and assessment strategies. Autoethnographical data reflects that one key strategy in realising this was that "…we were… determined that students would be in charge of marking themselves – deciding what their work was worth – similar to a workplace self-appraisal and then meeting with a team leader" (Entry C, 2021). To promote to students the idea that their agency was valued, students engaged in three fundamental types of assessment: student conferences, student interviews and project evaluations. Student conferences were designed to be a feedback-gathering tool, where students presented their project and the mid-way point of a project and gather feedback from both peers and teachers. Student interviews were designed to be a one-to-one conference between student and teacher, where the student brings evidence of the 21st century skills (QCAA, 2019, p. 2), and negotiates a grade with the teacher for their in-class performance against a rubric. Project evaluations were designed to be an evaluation of the project, from a students' perspective, with scaffolding to elicit reflections on both project- and self-management. An assessment rubric was developed based on the 21st century skills (QCAA, 2019), and then more recently, the General Capabilities (ACARA, 2018). The earliest expressions of STEM Studies at PCC had an ideological focus on student agency and mirroring assessment strategies with real-world instances of assessment.

After establishing assessment strategies, the focus of the middle enactment phase turned to connecting students with the wider world. One key strategy that PCC employed was a professional learning conference for students. "The PCC STEM Conference idea came from the need for students to widen their perspective of the types of problems they can solve" (Entry E, 2021). The purpose of the STEM Conference was to "…find a way to get lots of different professionals from a wide range of industries to speak about their jobs and the types of problems they faced, to inspire students to think bigger. At its conceptualisation, STEM conference was meant to be an idea-generating or inspiration tool" (Entry E, 2021). After the earliest expressions of STEM Studies at PCC focussed on student agency and assessment strategies, ideological focus shifted to connecting students' thinking and projects with authentic, real-world problems.

In the most recent enactment phase, the ideological focus shifted to reflections of the teacher's role within the STEM Studies subject at PCC. Administration and teaching staff both observe that the skills and pedagogies required to enact a strategy that aligns with policy purpose are often counterintuitive to the way teachers are generally trained and operate within their discrete classrooms. Administration staff observe that "to approach anything in a school from a transdisciplinary approach it not only goes against our training, but the way we form our institutions" (A2, p. 4), and "in terms of the skills that they need… it's not what comes naturally to teachers… it's actually quite challenging to switch to a different way of thinking" (A1, p. 7). Progressing towards curriculum innovation “demands that we view curriculum development from an entirely fresh perspective, one that moves beyond a compilation of information and skills to be methodically delivered to students” (Kaufman, Moss & Osborne, 2003, p. 2). This shift in mindset presents a significant challenge, given the socio-historic context of many curricula and the way that have traditionally been enacted in the education system. Costigan (2003, p. 15) suggests that there are a number of philosophical, cultural and practical boundaries in our education system that require close examination. Facilitating STEM education at PCC through a transdisciplinary approach, requires teachers to be lateral thinkers, rather than work in the linear processes that are common practice in educational systems.

Defining the PCC enactment strategy is a source of some nuanced tension between administration staff and teaching staff, despite alignment to descriptions of STEM education in policy. Whilst appearing to agree on the ideological purpose of STEM education, teaching and administration staff emphasise different aspects of enacting the transdisciplinary approach. For example, administration staff speak clearly about what they hope the program can achieve and include references to creating a “rich experience” for students (A2, p. 6). A2 describes the STEM Studies subject as “…a promotion of the group of subjects… but it produces something that’s truly pragmatic. Something that is tangible and that we can link to beyond school” (p. 3), and a place in which “I was inspired to think that our students could have a richer learning experience with the presence of a STEM program” (p. 6). In terms of outcomes for students, the perspective of administration staff focusses on highest level of ideological purpose, suggesting that they “…hope it will give tangible outcomes in terms of helping our kids lead their own learning journey, take risk, value agency and become good critical thinkers outside the creative subjects” (A2, p. 6), and “… our world needs creative people…and… that is going to be increasingly so in our future. That we’re going to need creative solutions to complex problems” (A2, p. 7). Teaching staff describe the ideological purpose of STEM Studies at PCC similarly, saying it is “…for the students to learn in a rich way what the 21st Century thinking skills are, in order for them to be innovative and adapt to a range of curriculum problems or life problems, to allow them to think collaboratively, think of other people’s needs, to change their plan along the way, while critically thinking and creatively thinking" (T2, p. 4). However, in contrast to the administration staff, teaching staff explicate a contemporary and grounded version of STEM education and can more clearly define the specifics of the PCC enactment strategy. For example, T1 describes the STEM Studies subject as "… more around the how do we bring those subjects together to solve problems? And how do we actually use them in real life?" (p. 2). T2 further expounds this idea to include "… trying to address the 21st Century thinking skills through engaging tasks that are generally centred around a project or… a wicked problem. But they are generally trying to address… future needs, while teaching the students about how to innovate or think creatively" (p. 2). A lack of clear, descriptive language for implementation in curriculum publications can be suggestive of flexibility, as autoethnographical data reflects that "… for all my discomfort or frustration with the lack of clarity – I probably wouldn't have been able to implement our particular STEM program if I was working with a prescriptive definition" (Entry R, 2021).

Three separate interview records state that the STEM Studies at PCC provides students with a "rich experience" of learning (A2, p. 6; T1, p. 9; T2, p. 4). This rich experience of learning within the STEM Studies subject is described as "…preparing the kids to think… what type of person are they going to be when they leave school and go into the workforce?" (T1, p. 9) and "… the world is changing… I don't know what it's going to look like, but we're going to need people to solve problems" (T1, p. 9). The nuanced word choices in these two statements suggests that the priority for teachers of STEM education at PCC is to prepare the person. By using the phrase "what type of person are they going to be" (T1, p.9), backed up by needing "people to solve problems" (T1, p.9) rather than people *who can* solve problems, the teaching staff reveal the enactment strategy has been influenced by the desire to prepare the whole person, rather than a set of skills, a knowledge base or technological competencies. This finding reveals a gap in current descriptions of STEM education. For example, Hobbs (2019) suggests that research in STEM education is developing, but that most examples of STEM education in schools are" locally developed and implemented so far-reaching effects are likely to be limited" (p. 226). Hobbs (2019) provides commentary on this thought, suggesting that research must now deepen to include factors "such as the need to attend to values, and student perceptions and conceptualisations” (p. 226). By attending to such things as values, a transdisciplinary approach to STEM can be seen to be “engaging in rich STEM experiences, [where] students develop a range of generic skills and ways of thinking that enable entrepreneurial behaviours, such as creativity, problem solving, critical thinking and communication skills” (Fraser et al., 2019, p. 10). With overarching goals such as national enterprise, maintaining prosperity and “not being left behind” (Hobbs, 2019, p. 222), STEM curriculum innovations should consider the perspectives of students and who they are when developing rich learning experiences.

Summary of Secondary Coding Domain: Ideologies

The PCC definition of STEM enactment endeavours to align as closely as possible with the policy language around the purpose of STEM, often against the grain of popular choices for STEM activities. The foci of each phase of enactment illustrate an evolving program that stemmed from a core driver of developing students’ whole person. In the pre-enactment phase PCC formed their ideology of STEM education in alignment with policy descriptions of the purpose of STEM, rather than implementation advice, which seemed to be very rare at the time. Then, the earliest expressions of STEM Studies at PCC had an ideological focus on student agency and mirroring assessment strategies with real-world strategies for project management and evaluation. As STEM Studies at PCC developed, ideological focus shifted to connecting students’ thinking and projects with authentic, real-world problems. In the most recent enactment phase, the ideological focus shifted to the teacher’s role within the STEM Studies subject at PCC. To facilitate the PCC approach to enactment of STEM education, with its intended purpose, requires teachers to be lateral thinkers, rather than work in the linear processes that naturally occur in educational systems. Finally, reflection reveals that the enactment strategy has been influenced by the desire to prepare the whole person, as opposed to a set of skills, a knowledge base, or technological competencies. This amounts to an approach unique to PCC STEM Studies.

5.4.5 Overall Summary: Results of Primary Coding Domain: Rules, structures, constraints, ideologies surrounding STEM curriculum implementation at the study site

The development, approval and subsequent enacting of the STEM curriculum innovation at PCC was subject to structures, constraints and ideologies. Documented rules that define and limit operationalisation of resources were not noted within this curriculum innovation. Initial approval and enactment were also not limited by timetabling and resources, due to circumstantial timetable gaps. Structures, considered enablers of the operationalisation, were focussed on curriculum and pedagogy. Curriculum and pedagogy decisions were driven by an attempt to align with policy descriptions of STEM education and the program was enacted in a transdisciplinary space with a focus on problem-framing, problem-solving and 21st century skills. Constraints of enactment that were identified focus on evaluative measures of the program. Without published success criteria or evaluative measures, the PCC curriculum innovation initially relied on anecdotal evidence of success within its context. The foci of each phase of enactment demonstrated an ideological connection between the policy descriptions of the purpose of STEM and the school's focus on developing students as people. Reflections of STEM teachers at PCC suggested that the role and characteristics of the teacher differ from discipline-based classrooms. Section 5.5 further investigates the character types and roles of individuals within the PCC STEM curriculum innovation.

5.5 Results of Primary Coding Domain: Character types or roles as individuals in implementing STEM curriculum at the study site.

The third primary coding domain aims to describe the character types and roles of actors within the PCC STEM enactment strategy. Analysis sought to identify character types and roles that actors had to assume during the STEM education enactment at PCC, even if outside of usual job descriptions. At PCC, the character types and roles including those of the actors are an important consideration of conceptualisation of the STEM curriculum innovation. Administration staff and teaching staff brought different character traits and role descriptions to the ideation, approval process and enactment of the STEM Studies subject. Analysis of the autoethnography and semi-structured interview data is listed in sections below, by secondary coding domains. Within each section, excerpts of primary data related to the secondary domain being discussed are presented in tables. This includes extracts of autoethnography data and extracts of semi-structured interview data. Analysis is then organised by chronological enactment phases, to demonstrate the range of behaviours, acts and activities that have been identified at each developmental stage of this case. Not all enactment phases are discussed in relation to each secondary coding domain; only those phases that were co-located in the data.

5.5.1 Secondary Coding Domain: Character types

The results in this section examine results in the secondary coding domain of character types, for both the autoethnography and semi-structured interview data. Within both autoethnographic and interview data, a range of character types taken by actors within the enactment process were described. Character types of teachers were a keen focus in this area. Excerpts of primary data are listed below in Table 25 (autoethnographic data), Table 26 (semi-structured interview data: administration perspective) and Table 27 (semi-structured interview data: teaching staff perspective). Character types are then discussed below, in chronological order of enactment phase.

Table 25.

Autoethnographic data: character types

Tertiary code	Quotes
Teacher/s	"The role of the teacher and the mindset of the teacher is so important" (Entry E, 2021) "…T2 integrated into the team perfectly. T2 was open to try new things, had a growth mindset and acknowledged that T2 wanted to learn how we do it. The observation period was so important - allowing T2 time to observe the ways we talk to students, how we interact with the class, how we question ideas and provide feedback." (Entry J, 2021) "I believe within our transdisciplinary approach to STEM, all teachers could provide unique knowledge, skills and perspectives that would be valuable resources to students in the class." (Entry T, 2021) "who a person is, their socialisation into the teaching profession, their educational philosophy and their futurist mindset all play integral roles in making someone a STEM teacher." (Entry T, 2021) "The natural style and flair of a teacher has to show through in the classroom. Teachers who are strict rule enforcers need to be accompanied by another teacher who can balance their approach. Key to their education philosophy needs to be an openness to take pedagogical risks, strong reflective practice, willingness to open their classroom to others (other teachers, professionals, etc), and a growth mindset in their approach to their own practice." (Entry T, 2021) **"**Some qualities or practices that would be harmful to the transdisciplinary approach would be a [unwavering] traditionalist view of education, where the teacher is the expert and the students are sponges, absorbing knowledge in a one-way transaction; a silent classroom; worksheet approaches; textbook teaching; pure chalk and talk all the time teaching" (Entry T, 2021)

Table 26.

Semi-structured interview data: administration perspective of character types

Tertiary code	Quotes
Teacher/s	"the teachers themselves need to be inquisitive. They need to actually see themselves as learners as well" (A2, p. 5) "… the teachers have to have those same thinking skills themselves" (A1, p. 7) Teachers need to be "comfortable with being responsive… In the moment they've got to be able to draw on what they know and decide on what's the best approach here for this student with this problem" (A1, p. 7 – but actually said by TD. A1 response is "Yeah absolutely") The teachers must "know where they want to go… but be able to roll with what the student's talking about or be able to facilitate the students working together. The staff need to have those skills, rather than just some knowledge" (A1, p. 7)

Table 27.

Semi-structured interview data: teaching staff perspective of character types

Tertiary code	Quotes
Teacher/s	"We have to have that mindset as well ourselves… those problem solving skills. All the skills we want to teach them I guess we need to have ourselves too" (T1, p. 6) "You need to be patient and have a bit of empathy as well. And just get alongside them and support them" (T1, p. 8) "Already being in that sort of field… and coming from an engineering field, I was quite interested in getting involved" (T1, p. 8). "I just love anything that's a new challenge… [and] teach[ing] innovative skills to students is something that really appeals to me." (T2, p. 7) "… teaching is a career [of] lifelong learning. A teacher never gets to a point and says, "I know everything." So, of course, you're always looking for further development" (T2, p. 6) "… I couldn't point to [things] in our course and say, "That's mine" or anything like that, because it's so entwined, because it was a team effort." (T2, p. 6) "… to collaborate with staff from other silos and different subjects, forces a different way of talking" (T2, p. 8) "…you come across something that's like, "This is different. Yeah, I'll give that a go." Then six years later you're sitting here going, "Yeah, that was a lot of work."" (T2, p. 7) "… you need staff who aren't afraid of innovating and having that fun, because I think some staff would be very scared if they – like just, "Hey, you're going to be collaborative teaching with someone from a different subject area to teach kids problem-based learning" and I can imagine that scaring some people" (T2, p. 8)

Identified in the recent enactment phase with a focus on evaluation of the curriculum innovation is the notion that the identity of a STEM teacher at PCC seems to stand in contrast to the policy language around who a STEM teacher is. References to STEM teachers are rare in policy, but when mentioned are most commonly characterised as people who are qualified to teach a discrete STEM subject, are an expert in a subject from the STEM suite or have previous qualifications and work experience in another STEM field (Education Council, 2018, p. 19). When describing STEM teachers within the case study, none of the interviewed parties mentioned specific qualifications or teaching areas, but rather the character traits of the person that were important in enactment. Interviews with administration staff identified clear character traits, and the teaching staff focussed on the mindsets and actions of teachers needed to facilitate the pedagogical approach employed by PCC.

Administration staff suggest that “the teachers themselves need to be inquisitive. They need to actually see themselves as learners as well” (A2, p. 5). This temperament of inquiry is echoed by A1, who suggests that teachers need to be “comfortable with being responsive… in the moment they’ve got to be able to draw on what they know and decide on what’s the best approach here for this student with this problem” (p. 7). Throughout the two administration staff interviews, there was a strong focus on teachers needing to “…have those same thinking skills themselves” (A1, p. 7), and being able to facilitate the needs of students, “rather than just some knowledge” (A1, p. 7). This perspective is demonstrated by teaching staff in the PCC context, who reflected that “I just love anything that’s a new challenge…[and] teach[ing] innovative skills to students is something that really appeals to me” (T2, p. 7). From an administration perspective, the character of a STEM teacher is one who is inquisitive and responsive, which are identified as two skills that the STEM Studies program at PCC is trying to develop in students.

Teaching staff focus on the mindsets and actions of teachers needed to facilitate a responsive pedagogy of inquiry and thinking. Teaching staff agree with administration staff, suggesting that “who a person is, their socialisation onto the teaching profession, their educational philosophy and their futurist mindset all play integral roles in making someone a STEM teacher” (Entry T, 2021). “We have to have that mindset as well ourselves… those problem-solving skills. All the skills we want to teach them I guess we need to have ourselves too” (T1, p. 6). Specific aspects of the PCC STEM teacher mindset that were identified by teaching staff are patience and empathy, a learner’s mindset, a collaborative mindset and a give-it-a-go attitude. When reflecting on how teachers interact with students, T1 suggests that “you need to be patient and have a bit of empathy as well. And just get alongside them and support them”. T2 suggests that teachers should employ a learner’s mindset, saying “teaching is a career [of] lifelong learning. A teacher never gets to a point and says, “I know everything”. So of course, you’re always look[ing] for further development” (p. 6). A mindset that prioritises collaborative efforts was important in the development of the STEM Studies subject, as outlined by T2, who reflects that "… I couldn't point to [things] in our course and say "that's mine" or anything like that because it's so intertwined, because it was a team effort" (p. 6) and "… to collaborate with staff from… different subjects, forces a different way of talking" (p. 8). The final character trait identified by teaching staff is less tangible and exists as an attitude towards trying something new. T2 reveals this characteristic in the sentiment of "…you come across something that's like, "This is different. Yeah, I'll give that a go". Then six years later you're sitting here going "Yeah, that was a lot of work"." (p. 7). Teaching staff seem to agree that the person a teacher is and their mindset towards the purpose of STEM education are more important when classifying someone as a STEM teacher. "I believe within our transdisciplinary approach to STEM, all teachers could provide unique knowledge, skills and perspectives that would be valuable resources to students in the class" (Entry T, 2021).

Along with the character types that are valued in and by STEM teachers at PCC, several character traits are viewed as inhibiting enactment of the transdisciplinary pedagogical framework. "Some qualities or practices that would be harmful to the transdisciplinary approach would be a traditionalist view of education, where the teacher is the expert and the students are sponges, absorbing knowledge in a one-way transaction; a silent classroom; worksheet approaches; pure chalk and talk all the time teaching" (Entry T, 2021). Though, it seems that the collaborative approach to teaching favoured by PCC can help dilute characteristics that may be harmful to the process. "The natural style and flair of a teacher has to show through in the classroom. Teachers who are strict rule enforcers need to be accompanied by another teacher who can balance their approach." (Entry T, 2021). An example of how to approach this collaborative pedagogy can be seen as autoethnographical data reflects on training a new teacher. "…T2 integrated into the team perfectly. T2 was open to try new things, had a growth mindset and acknowledged that T2 wanted to learn how we do it. The observation period was so important – allowing T2 time to observe the ways we talk to students, how we interact with the class, how we question ideas and provide feedback" (Entry J, 2021). Whilst the rigidity of a traditionalist view of classrooms may not be conducive to the pedagogy of STEM

Studies at PCC, within a collaborative teaching relationship, it can be balanced into a positive environment for students.

Summary of Secondary Coding Domain: Character Types

Synthesis of administration and teaching staff views yields a concise list of personal characteristics and mindsets of who a STEM teacher is at PCC. In essence, a STEM teacher at PCC is one who is inquisitive and responsive, patient and empathetic in the classroom, views themselves as a learner, and possess themselves the skills they are trying to build in students. “Key to their education philosophy needs to be an openness to take pedagogical risks, strong reflective practice, willingness to open their classroom to others (for example other teachers or professionals) and a growth mindset in their own approach to their practice” (Entry T, 2021). Whilst there are certain personal characteristics or pedagogical choices that can limit the enactment strategy employed by PCC, a collaborative approach can help balance the environment.

5.5.2 Secondary Coding Domain: Assumed Character Types

The results in this section examine results in the secondary coding domain of assumed character types, for both the autoethnography and semi-structured interview data. Character types that were assumed by actors within the enactment process were described in both autoethnographical and interview data. Assumed roles considered were that of teachers, curriculum leaders and administration. Excerpts of primary data are listed below in Table 28 (semi-structured interview data: administration perspective). Assumed character types are then discussed below, in chronological order of enactment phase.

Table 28.

Semi-structured interview data: administration perspective of assumed character types of teachers

Tertiary code	Quotes
Teacher/s	"[staff members] need to be collaborative [and]… because of the newness of it, [have] a fair bit of innovation and creativity" (A2, p. 4) "if you've got somebody passionate to pursue a project, then that's half the battle won" (A2, p. 5) "… staff who are passionate and well informed" (A1, p. 10) "I'm inspired to think we can have me really great critical and creative and innovative people subjects that are not stereotypically creative" (A2, p. 6). "I'd love to see some creativity in our school that doesn't revolve around the humanities and the arts" (A2, p. 7) "I would love to get into the classroom and be involved in that. But I think it's a challenge for me, because my thinking has been a certain way for so long, how well would I do in that?" (A1, p. 8)

Throughout the evaluative phase of enactment, administration staff reflect on assumptions about the characteristics of teachers who they consider suitable to teach the STEM Studies subject. Administration staff's perspective is that the first people on a project need to be passionate. "If you've got somebody passionate to pursue a project, then that's half the battle won" (A2, p. 5), and reiterated by A1 who states that innovative enactment strategies require "… staff who are passionate and well informed" (p. 10). Administration staff further describe character types they would like to see in teachers of STEM Studies at PCC, with A2 reflecting that "I'm inspired to think we can have really critical and creative and innovative people in subjects that are not stereotypically creative" (p. 6) and "I'd love to see some creativity in our school that doesn't revolve around the humanities and the arts" (p. 7). When reflecting on the assumed characteristics of teachers in the STEM Studies classroom at PCC, A1 expressed a desire to enter the classroom in a teaching capacity but articulated that it would be challenging in terms of mindset. This may be representative of how teachers may feel before embarking on an innovative pedagogical journey, requiring them to assume characteristics such as boldness or courage. "I would love to get into the classroom and be involved in that. But I think it's a challenge for me, because my thinking has been a certain way for so long, how well would I do in that?" (A1, p. 8). Administration staff highlight that to teach within the PCC STEM enactment strategy, teachers must be willing to engage with challenges that require courage.

Summary of Secondary Coding Domain: Assumed Character Types

Administration staff reflect that there are several characteristics that they assume of teaching staff within the PCC context. Teachers' character types are described as passionate, well-informed, critical, creative and innovative (A1, p. 10; A1, p. 6). A1 also describes teaching within the PCC pedagogical framework as challenging and implies that a teacher asked to teach STEM Studies would need the courage face this challenge.

5.5.3 Secondary Coding Domain: Roles

The results in this section examine results in the secondary coding domain of roles, for both the autoethnography and semi-structured interview data. Within both autoethnographic and interview data, a range of roles assumed by actors within the enactment process were described. Roles considered were that of teachers and administration staff. Excerpts of primary data are listed below in Table 29 (autoethnographic data), Table 30 (semi-structured interview data: administration perspective) and Table 31 (semi-structured interview data: teaching staff perspective). Roles are then discussed below, in chronological order of enactment phase.

Table 29.

Autoethnographic data: roles

Tertiary code	Quotes
Teacher/s	"The team-teaching aspect of our enactment strategy is crucial to the success of the whole operation" (Entry O, 2021) "it's a whole different mindset from my other classes. I often use the walk between classes to reset my mind - to change from the structured minute-by-minute plan I have in my Maths or Science classes, to the problem-based questioning style of facilitative teaching that I use in the STEM classroom." (Entry U, 2021)

Table 30.

Semi-structured interview data: administration perspective of roles

Tertiary code	Quotes
Teacher/s	"the staff work in teams" (A1, p. 5) "collaborative teams" (A1, p. 7) Teachers will have "…training on… a whole range of different types of pedagogies to be able to pick and choose from them for what's needed in the moment" (A1, p. 7) "…instead of seeing that* as incompetence, it's actually realizing that that is modelling how these students are probably going to be working in their workplaces" (A1, p. 9) "…teachers have a really important part to play in modelling… collaboration between teachers and… drawing on each others' strengths" (A1, p. 9).
Administration	Students were coming to me pitching what they wanted to solve" (A1, p. 5)

Table 31.

Semi-structured interview data: teaching staff perspective of roles

Tertiary code	Quotes
Teacher/s	"… I see my role more… as a facilitator and… a prompter. [However]… there are certain skills that they do need to be taught. There is an element of direct instruction for certain things." (T1, p. 4) "… if they haven't come across those topics in Maths, for example… there might be a situation where we have to teach that directly.". (T1, p. 4) "what's really important… is having a teacher who can recognize when they need to work responsively… [and] that it's an approach that requires you to look at who's in the room, look at the problem that's been framed up, and then to be able to reach out to whatever approach you need to help facilitate a resolution" (T1, p. 5 – but said by TD. T1 responded with "Yeah, that sounds about right").

In the recent enactment phase, the roles of the teachers and administration staff within the curriculum innovation were considered. Each of these two groups of people played significant roles in the physical enactment of STEM education at PCC. Both groups were able to consider their own role, as well as the role of the other group and the skills required to enact STEM Studies at PCC.

Administration staff perceive that the role of the teacher is to model current and future workplace structures and functions. When reflecting on utilising a responsive pedagogy, A2 suggests that "instead of seeing that [flexibly responding to students' needs] as an incompetence, it's actually realising that that is modelling how these students are probably going to be working in their workplaces" (p. 9). Teaching staff describe the teacher's role as facilitating learning, however that looks on the day. Sometimes it can mean direct instruction in skills and knowledge, or it can also mean flexibly responding to student identified needs. "… I see my role more… as a facilitator and prompter. [However]… there are certain skills that do need to be taught. There is an element of direct instruction for certain things (T2, p. 4). An example of a direct instruction moment is described by A2 during a data interpretation lesson, "… if they haven't come across those topics in Maths, for example… there might be a situation where we have to teach that directly" (p. 4). Autoethnographical data further explicates the notion of acting as facilitators, stating "…it's a whole different mindset from my other classes. I often use the walk between classes to reset my mind – to change from the structured minute-by-minute plan I have in my Maths or Science classes, to the problem-based questioning style of facilitative teaching that I use in the STEM classroom (Entry U, 2021). Hobbs (2019) suggests that approaching STEM education as both a discipline and a pedagogy facilitates an integrative view of learning, that enabled "deeper engagement with the problem-solving process" (p. 223). Hobbs (2019) suggests drawing in a range of useful pedagogies, such as "multi-modalities and representational pedagogy" (p. 223), where disciplines provide context for explorations across the fields. The PCC STEM Studies subject approaches STEM education with pedagogical flexibility, with teaching staff acting as facilitators of learning through problem-solving.

Both administration and teaching staff agree that collaboration is crucial to the transdisciplinary pedagogy employed by PCC, suggesting that collaboration extends beyond teachers working as a team, to students working on a project and between teacher and student, to facilitate learning. A2 suggests that "the staff work in teams" (p. 5), and "teachers have a really important part to play in modelling… collaboration between teachers and… drawing on each other's strengths" (p. 9). Teaching staff further iterate that "the team-teaching aspect of our enactment strategy is crucial to the success of the whole operation" (Entry O, 2021). PCC favours having a teacher who can recognise when they need to work responsively; an approach that requires a teacher to take into account the learners and the problem that's been framed up before reaching out to whatever approach is required to help facilitate a resolution.

When considering the role of administration staff in the most recent enactment phase, it is clear that the administration staff were intentionally included as actors in the STEM Studies subject. Autoethnographical data reflects that,

> …we included leadership as players in the students' problem solving in a range of ways: A1 would come into class and "give evidence" in the [Term 1 project problem-framing session], and A2 would listen to pitches from groups of students. This started out as a thought to showcase the program to leadership so that they would know what we were doing but… it had the unintentional benefit of helping them buy-in to the program. Because they felt like they were a part of it, they would respond with trust in us, our methods and ideologies. (Entry W, 2021)

Administration staff also engage with students in the STEM class by listening to student pitches if they involve actions on the school site. They give approval or non-approval to implement projects at school, as A1 reflects "students were coming to me pitching what they wanted to solve" (p. 5). Including administration staff as actors in STEM enactment strategy at PCC for the purpose of understanding and awareness may have contributed to the perceived success of the program, and also created some influence in the future of the program.

Summary of Secondary Coding Domain: Roles

In the evaluative phase of enactment at PCC, the roles of both the administration staff and the teaching staff have been generally identified. The administration staff's perspective of the teacher's role is to model current and future workplace structures and functions. The teaching staff's perspective of the teacher's role as a facilitator of learning, which assumes a responsive pedagogy of flexibly approaching lessons and students. Administration staff see their own role as primarily one of giving approval to students wanting to implement projects on school site, however, teaching staff have intentionally included administration staff as actors in the classroom by engaging them with specific activities and by listening to student pitches. Both administration and teaching staff agree that a key role for all actors to model within this enactment strategy is that of collaborative work.

5.5.4 Secondary Coding Domain: Assumed Roles

The results in this section examine results in the secondary coding domain of assumed roles, for both the autoethnography and semi-structured interview data. Throughout the PCC enactment of STEM education, there have been times that actors have assumed roles including curriculum leaders and cultural change agents, that are outside of their regular job description. This can be for a range of reasons. Within both autoethnographic and interview data, a range of roles that were assumed by actors within the enactment process were described. Roles considered were that of administration, teachers and curriculum leaders. Excerpts of primary data are listed below in Table 32 (autoethnographic data) and Table 33 (semi-structured interview data: administration perspective). Roles are then discussed below, in chronological order of enactment phase.

Table 32.

Autoethnographic data: assumed roles

Tertiary code	Quotes
Administration	"… For months, we found it difficult to… communicate… We basically communicated through a mediator / third party. After the conference was over… we were able to continue working..." (Entry F, 2021)

Table 33.

Semi-structured interview data: administration perspective of assumed roles

Tertiary code	Quotes
Teacher/s	"I'm excited to think we could have a faculty that is dedicated to inspiring students to be critical thinkers. To be problem solvers. To be engaged in solving real world problems. And using their Maths and Science, all of those things" (A2, p. 7)
Curriculum leader/s	"Early on, when we were discussing this, [teacher] brought research forward, and put forward the proposal… that the thinking skills [students would develop] would help any subject" (A1, p. 4) "[teacher] had done so much research beforehand – [they]'d gone to schools, [they]'d gone to professional development, [they] had done the readings – that gave me that sense of security in that okay, this is worth the risk" (A1, p. 9) "… it's been good in modelling to the rest of the school, trying something new, doing some research, getting outside of… do[ing] what we always do" (A1, p. 11) "… it's constantly… there as that little bit of challenge to our thinking." (A1, p. 11) "… we've started some broader discussions as… we've got his case study sitting there as a success". (A1, p. 11)

Throughout the pre-enactment phase**,** before the STEM Studies subject was approved for implementation at PCC, two teachers assumed the roles of curriculum leaders and perceived experts in STEM education. To enact this project, the school required a research-focussed curriculum leader to manage the risk of acting without a secure reality. It was clear at this point that this was a process of enacting policy, because in this instance, realities were not secure but instead had to be practised (Heimans, Singh & Glasswell, 2015, p. 188). At PCC, the administration staff responsible for the approval to implement trusted the proposal put forward because it was research based. "Early on, when we were discussing this, [teacher] brought research forward and put forward the proposal" (A1, p. 4). Trust was held in the proposal because [teacher] and [teacher] had "done so much research beforehand… gone to schools… gone to professional development… done the readings – that gave me a sense of security in that okay, this is worth the risk" (A1, p. 9). To enable the STEM Studies subject to be approved for implementation at PCC, teachers assumed the role of curriculum leader and research-focussed STEM education experts.

Throughout the middle enactment phase, conflicts arose between actors from time to time. The first chronological instance of conflict occurred between teaching staff, who identified an instance in which "…we found it difficult to…communicate. We basically communicated through a mediator" (Entry F, 2021). This instance of conflict occurred throughout the development of a STEM Conference, designed to be a professional learning opportunity for students at PCC. "[M]ission drift" (Entry F, 2021) was also identified as a source of conflict, which occurred as the teaching and learning of the curriculum innovation drifted away from the original intentions. Conflict occurred when teaching staff were no longer able to function in a team-teaching environment due to timetabling constraints, and when administration staff introduced school-based priorities for the STEM Studies program, such as needing to align the content being taught with senior college subjects reflects that:

> In 2019, the STEM program was extended to Year 9, and the teaching responsibilities were divided. Up until this point… [it was] team-teaching one class in one room. In 2019, [teacher] took over the Year 9 program, and [teacher] continued to refine the Year 10 program. [Teacher]'s Year 9s became more about the short term… skills-building projects. (Entry F, 2021)

Autoethnographical data further outlines that when curriculum pressures of leading into senior college subjects were applied, these requirements were in ideological conflict to the original intentions of the curriculum innovation at PCC, saying:

> … there was further mission drift between the STEM teachers and the Administration. Administration asked that we make STEM a "Pre-Engineering" course, with a focus on leading students into the Year 11-12 Engineering course. This was in direct conflict with the heart of the program, which was focussed on problem-solving and soft skills that students can then take into ANY course, academic or otherwise, that they complete in Year 11-12 (Entry F, 2021).

Throughout the middle enactment phase, conflicts arose within the PCC STEM education enactment strategy, due to ideological tensions between the teaching staff of the subject, as well as between teaching and administration staff.

Within the recent enactment phase, which focussed on evaluative reflections, administration staff describe the roles that they hope teachers can play in enacting the PCC strategic vision for students. “I’m excited to think that we could have a faculty that is dedicated to inspiring students to be critical thinkers. To be engaged in solving real world problems” (A2, p. 7). In doing this, STEM teachers at PCC have assumed the role of change agents within the contextual PCC approach to education. A1 suggests that “…it’s been good modelling to the rest of the school, trying something new, doing some researching, getting outside of… do[ing] what we always do” (p. 11), and “… we’ve started some broader discussions as… we’ve got this case study sitting there as a success” (p. 11). Noting the description of the STEM Studies implementation case as a “success” (A1, p. 11) within the PCC context implies that the research-based design of the subject, alongside the alignment to the strategic vision of the school, may have been influential in gaining approval to enact.

Summary of Secondary Coding Domain: Assumed Roles

Throughout the PCC enactment of STEM education, there have been times that actors have assumed roles that are outside of their regular job description. In the early stages of the enactment strategy, teachers acted as curriculum leaders to design a research-based enactment strategy; a process that was valued by the administration staff who were looking to approve the subject. However, upon reflection, administration staff highlighted that the design of the STEM Studies subject needed to be both research-based and aligned to the PCC strategic vision for students. In doing this, the case of STEM Studies at PCC was characterised as a “success” (A1, p. 11) from an administration staff perspective.

5.5.5 Overall Summary: Primary Coding Domain: Character types or roles as individuals in implementing STEM curriculum at the study site.

A range of character types and roles, both apparent and assumed, of the teaching and administration staff within the PCC curriculum innovation emerged from the data collected. Character types of teachers were considered and found that some characteristics such as inquisitiveness and empathy were found to be enablers in the enactment process. Teaching staff and administration staff played different roles within the development, approval and enactment of the curriculum innovation. Administration staff primarily view their role as approval givers, and occasionally are involved in the classroom. Teaching staff characterised their role as a facilitator of learning, which assumes a responsive pedagogy and flexibly approaches the learning environment. Assumptions about character types and roles centralised around risk-taking, and the characteristics such as courage that were required to do so. Teachers particularly had to assume roles such as curriculum leaders, to ensure the enactment strategy was research-based and experienced continual reflection and evaluation. With these understandings of the character types and roles of the staff enacting the STEM education curriculum innovation at PCC, the research now turns to summarising the key findings of analysis.

5.6 Summary of key findings from analysis of autoethnographical and semi-structured interview data

Research question two of this descriptive, instrumental case study states "how is one example of middle-school STEM curriculum conceptualised at one Independent Secondary School in Queensland?". To conceptualise the STEM Studies program at PCC, autoethnographical and semi-structured interview data have been analysed using phronetic iterative analysis (Tracey, 2019). A summary of the key findings is presented below, in relation to each secondary coding phrase.

5.6.1 Goal oriented behaviours, acts of activities

At PCC, the goal of implementing a timetabled STEM subject for Years 9 and 10 students that aligned with policy descriptions of STEM education that included problem-solving or future-focussed skills (ACARA, 2016a; Department of Education and Training, 2017; Education Council, 2015, 2019; OCS, 2013, 2014; QCAA, 2019, Rosicka, 2016) was addressed throughout enactment. A convenient gap within the secondary timetable was identified, and a transdisciplinary curriculum was developed for enactment. Throughout the early years of enactment, the types of problems that students addressed within the subject became increasingly authentic and meaningful through a negotiation process that iteratively occurred between students, teachers and administrators regarding a definition of what constitutes a "real-world" problem. The PCC enactment strategy had an implicit goal of leading change in STEM curriculum enactment, which is addressed through a view of STEM education as transdisciplinary, complemented by contemporary classroom techniques such as a responsive pedagogy and problem-framing and open-ended problem-solving.

5.6.2 Emotion oriented behaviours, acts or activities

The staff involved in the development and enactment of the STEM curriculum innovation at PCC displayed emotion-oriented actions. STEM Studies at PCC was initially conceptualised through strong emotional responses in teaching staff to policy imperatives that prepare students for a national agenda that includes national enterprise, sustaining economic growth, maintaining prosperity and “not being left behind” (Hobbs, 2019, p. 222). Teachers’ perceptions of student responses to the challenges of working in a classroom different from their other classes were characterised through emotional behaviours. For instance, teaching staff described the students’ frustrations within the classroom, when they met challenge points in their learning. However, students’ personal growth was described positively when it was observed by administration staff outside the classroom. Concerns about future iterations of the STEM Studies subject demonstrate the administration staff’s feeling the emotional burden of policy language and looking to widen the impact of the STEM Studies program at PCC.

5.6.3 Rules

Throughout the review process, there were no clear occurrences of rules that have been made or implemented within the PCC STEM enactment strategy. This is an important gap in the current understanding of how STEM education is conceptualised, the underpinning policy and contemporary enactment advice. This silence speaks to the lack of clarity in the definition and implementation advice for STEM education that is available.

5.6.4 Structures

PCC devised a school-based curriculum that focused on assessment strategies that mirror workplace interactions and collaboration, experiential learning, problem-framing, problem-solving and 21st century skills; each of these being priorities that align with policy descriptions of STEM education (ACARA, 2016a; DESE, 2016; DESE, 2019; DET, 2017; Education Council, 2015, 2019; Lowrie et al., 2017; OCS, 2013, 2014; QCAA, 2017; Rosicka, 2016). The structure of the PCC STEM Studies curriculum acknowledges that discrete knowledge bases and subject specific skills can be learnt, mastered and practised within the class time of each subject such as Science and Mathematics, which are commonly taught and assessed in Australia using specialised classrooms and the Australian Curriculum (ACARA, 2018). However, the role of STEM is to use discipline-based knowledge and skills within a transdisciplinary framework, focussed on problem-solving. Enactment of a cross-disciplinary STEM education curriculum challenges students to think and work in innovative and different ways.

5.6.5 Constraints

Within this case study, timetabling was not an initial constraint, as there was a convenient gap within the timetable. Leadership recognised risk was inherent in trialling a new pedagogical strategy but were willing to take this risk when presented with a research-based case. However, when faced with the desire to expand the STEM Studies curriculum to other areas of the school, difficulties finding room within the timetable emerged. Further potential constraints are identified as considering the inherent risks to schools in enacting curriculum innovations. This constraint was overcome in the PCC context, with administration staff who are willing to take this risk with curriculum time, teacher timetables or resources, with the hope of creating meaningful growth in 21st century skills for students. Success criteria for enactment strategies of STEM education cannot currently be informed by agreed systemic criteria as these do not exist. However, at PCC the enactment of STEM is considered successful by both teaching and administration staff due to the growth in student 21st century skills measured by fit-for-purpose assessment items.

5.6.6 Ideologies

STEM enactment at PCC endeavours to align as closely as possible with the policy imperatives (ACARA, 2016; DESE, 2016; DESE, 2019; DET, 2017; Education Council, 2015; 2019; Lowrie et al., 2017; OCS, 2013, 2014; QCAA, 2017; Rosicka, 2016). Each enactment phase illustrates an evolving program that is driven by the intention of developing students' whole person. The earliest expressions of STEM Studies at PCC had an ideological focus on student agency and mirroring assessment strategies with real-world instances of assessment. The next iteration of the program at PCC focussed on student agency and assessment strategies. Here, ideological focus shifted to connecting students' thinking and projects with authentic problem-solving. In the most recent enactment phase, the ideological focus highlighted the teacher's role within the STEM Studies subject at PCC. To facilitate the PCC approach to enactment of STEM education, teachers are challenged to think outside the linear processes of knowledge bequeathment that generally occurs in educational systems. Finally, reflection reveals that the enactment strategy has been influenced by the desire to prepare the whole person, rather than a just set of skills, a knowledge base or technological competencies that seem to be the focus of other STEM enactment strategies.

5.6.7 Character types

A list of personal characteristics and mindsets of PCC STEM teachers was developed by both administration and teaching staff. In essence, a STEM teacher at PCC is one who is inquisitive and responsive, patient and empathetic in the classroom, views themselves as learners, and possess themselves the skills they are trying to build in students. A STEM teacher at PCC has a personal educational philosophy includes openness to risk, reflective practice, open classrooms and a growth mindset. Whilst there are certain personal characteristics or pedagogical choices that can limit the enactment strategy employed by PCC, a collaborative approach and team-teaching can help balance the environment. Administration staff reflect that there are several characteristics that they assume of teaching staff within the PCC context. Teachers' character types are described as passionate, well-informed, critical, creative and innovative. Administration staff at PCC also describe teaching within the PCC pedagogical framework as challenging and imply that a teacher asked to teach STEM Studies would need the courage face this challenge.

5.6.8 Roles

The roles of administration staff and the teaching staff within the PCC enactment strategy are described in general terms. The administration staff's perspective of the teacher's role is to model current and future workplace structures and functions. The teaching staff's perspective of the teacher's role as a facilitator of learning, which assumes a responsive pedagogy of flexibly approaching lessons and students. Administration staff see their own role as primarily one of giving approval to students wanting to implement projects on school site, however, teaching staff have intentionally included administration staff as actors in the classroom by engaging them with specific activities and by listening to student pitches. Both administration and teaching staff agree that a key role for all actors to model within this enactment strategy is that of collaborative work. Throughout the PCC enactment of STEM education, there have been times that actors have assumed roles that are outside of their regular job description. Early within the enactment strategy, teachers acted as curriculum leaders to design a research-based enactment strategy, a process that was valued by the administration staff who were looking to approve the subject. However, upon reflection, administration staff highlighted that the design of the STEM Studies subject needed to be both research-based and aligned to the PCC strategic vision for students. In doing this, the case study was characterised as a “success” (A1, p. 11) from the perspective of administration staff.

5.7 Conclusion: Research Question 2: How is one example of middle-school STEM curriculum conceptualised at one Independent Secondary School in Queensland?

STEM Studies at PCC values policy aligned STEM curriculum enactment and has been conceptualised through investigation of goal-oriented and emotion-oriented acts and behaviours; rules, structures, constraints and ideologies; character types and roles of actors. Each of these avenues of investigation point to contemporary pedagogical techniques such as a responsive pedagogy that utilises visions of future workplaces and innovative problem-solving. Concerns about future iterations of the STEM Studies subject demonstrate the heavy burden of policy language. There were no clear occurrences of rules that have been made or implemented within the PCC STEM enactment strategy. The PCC enactment strategy devised a school-based curriculum that focused on authentic assessment strategies, cognitive dissonance experiential learning, problem-framing, problem-solving and 21st century skills (QCAA, 2019). At PCC, assessment is designed to measure growth in students’ 21st century skills, however up until now firm success criteria from an organisational viewpoint relies heavily on anecdotal evidence. Reflection reveals that the enactment strategy has been influenced by the desire to prepare the whole person, rather than a just set of skills, a knowledge base or technological competencies that seem to be the focus of other STEM enactment strategies. Whilst there are certain personal characteristics or pedagogical choices that can limit the enactment strategy employed by PCC, a collaborative approach and team-teaching can help balance the environment. Both administration and teaching staff agree that a key role for all actors to model within this enactment strategy is that of collaborative work. Teachers' character types are described as passionate, well-informed, critical, creative and innovative (A1, p. 10; A1, p. 6). A1 also describes teaching within the PCC pedagogical framework as challenging and implies that a teacher asked to teach STEM Studies would need the courage face this challenge. However, upon reflection, administration staff highlighted that the design of the STEM Studies subject needed to be both research-based and aligned to the PCC strategic vision for students. Through these investigations, it can be demonstrated that the PCC enactment of STEM education is conceptualised as a transdisciplinary, problem-focussed curriculum, that utilises teachers as facilitators of learning in a contemporary educational environment.

The research herein now turns to provide a synthesis of results and analysis and to distil any critical principles of enactment from PCC's curriculum innovation that could potentially be transferred to other settings. The transferrable principles derived from the resolution of the third research question, which states 'What are the critical principles of enactment to enable the PCC STEM curriculum to be transferred to another school setting?' will be addressed in Chapter Seven: Synthesis.

Chapter 6: Synthesis

Research Question Three states "What are the critical principles of enactment to enable the case study's STEM curriculum to be transferred to another school setting?". The following chapter will synthesise the findings of policy analysis and analysis of primary data collection within this research to distil the critical principles of enactment, that have the potential to be transferred to other school settings. Findings will be discussed in chronological order of enactment phases, to highlight transferrable principles that will be relevant for other settings at a range of stages of enactment.

6.1 Synthesis: Pre-enactment phase

The pre-enactment phase at PCC is characterised by emotive responses to policy imperatives, the designing and approval of a STEM subject within curriculum time and overcoming the constraints of implementing a new subject.

The disparity between the purpose and conceptualisation of STEM education in policy created confusion for teachers looking to enact a STEM education curriculum innovation at PCC. It appeared that policy definitions did not agree on a prescriptive description of what STEM education is, but rather employed a duality of definitions that allow for a range of implementation strategies to be classified as STEM education (ACARA, 2016; DESE, 2016; DESE, 2019; DET, 2017; Education Council, 2015, 2019; Lowrie, Downes & Leonard, 2017; OCS, 2013, 2014; QCAA, 2017; Rosicka, 2016). The spectrum of definitions including both discipline-based and integrated cross-discipline definitions allow for creative expressions of STEM education, however, the polysemy led to teaching staff describing feelings of confusion and guilt over PCC's inaction in the STEM space. This emotional driver led to the development of the STEM Studies subject, as teaching staff assumed the roles of curriculum leaders and presented a research-based proposal for a transdisciplinary, problem-focussed subject. Administration staff saw the proposal as something important that was missing from students' current experience of school at PCC and had trust in the teachers acting as curriculum leaders to manage the risk of implementing an untested subject in curriculum time. The combination of a convenient gap in the secondary school timetable alongside a pedagogical approach that didn't require costly resources, allowed for a straightforward approval process of a transdisciplinary enactment of STEM education.

Transdisciplinary STEM education enacted in curriculum time presents schools with challenge. Staff at PCC reflect that there are several constraints that could influence another school's ability to approve a similar enactment to PCC's STEM Studies subject. The constraints identified by PCC staff are timetabling, risk management, the characteristics required of transdisciplinary STEM teachers and training teachers to act outside normal classroom pedagogies. Administration staff reflected that the space between enactment ideation and implementation can be problematic, and in many cases, it may be easier to stay in extra-curricular time and activities. The pre-enactment phase at PCC is characterised by emotive responses to policy imperatives, the designing and approval of a STEM subject within curriculum time and overcoming the constraints of implementing a new subject.

Critical principles of enactment that emerged in the pre-enactment phase at PCC are STEM education definitions, strategic pedagogical decisions, the ability to overcome logistical constraints and personal characteristics of the administration and teaching staff. Central to the PCC enactment strategy is the school's choice to align with a definition of STEM education characterised as transdisciplinary, rather than discipline-based, multidisciplinary or interdisciplinary, in an effort to enact the highest level of integration. As suggested by Helmane and Briska (2017) and Kaufman, Moss and Osborn (2003), a transdisciplinary approach is organised around student questions and concerns, utilising knowledge and skills from a range of disciplines, and represents the highest level of integration, or cross-discipline teaching and learning. This approach provided foundational structure to enact policy language such as real-world problem solving and 21st century learning and future-focussed ways of working (ACARA, 2016; DESE, 2016; DESE, 2019; DET, 2017; Education Council, 2015, 2019; Lowrie, Downes & Leonard, 2017; OCS, 2013, 2014; QCAA, 2017; Rosicka, 2016). Strategic pedagogical decisions to organise the curriculum around student questions with a focus on real-world problem-solving meant that costly resources such as robotics kits and drones were not needed to initially enact the program. What was required, however, was teaching staff who were willing to take pedagogical risks and an administration staff who were willing to manage the logistics and risks of implementing novel curriculum.

6.2 Synthesis: Early enactment phase (Year 1)

The first year of STEM Studies enactment at PCC saw a focus on building opportunities for students to understand and manifest their own agency and training students in non-traditional assessment strategies. Student agency was viewed by staff as an important step away from traditional classrooms, where students are generally producing work that they feel meets a teacher's expectations, rather than creating authentic solutions to real-world problems. The perspective of students as young Australians with the future of the nation to consider was explicitly emphasised in classroom activities and assessment strategies. Assessment types included student conferences, student interviews and project evaluations, that were specifically designed to mirror workplace evaluations of staff and projects. Assessment rubrics were developed based on QCAA's (2019) 21st century skills.

In the earliest enactments of STEM education at PCC, negotiation had to occur around the types of problems that would be acceptable for students to address. Emerging through student-staff interactions associated with pitching projects, it was recognised that students didn't understand their charge of tangibly enacting solutions to real-world problems. The PCC enactment strategy evolved at this point, to ensure it valued and clearly addressed the authentic, contextual and problem-solving approach that is outlined in policy documentation (ACARA, 2016; DESE, 2016; DESE, 2019; DET, 2017; Education Council, 2015; Lowrie et al., 2017; OCS, 2013, 2014; QCAA, 2017; Rosicka, 2016). The first lessons learnt during enactment at PCC were that students needed training to work outside the regular classroom requirements of producing work that meets a teacher's expectations of a task, rather than objective solutions that address a well-framed problem. Assessment tasks at PCC were designed to mirror real-world experiences of conferences, interviews and project evaluations, and were assessed using a PCC designed rubric based on the 21st century skills (QCAA, 2019, p. 2).

Critical principles of enactment that emerged during the early enactment phase at PCC were a tangible prioritisation of student agency within the curriculum and the development of non-traditional but fit-for-purpose assessment strategies. Transdisciplinary approaches to teaching and learning demand that curriculum should be organised around student questions and concerns, suggesting that the student voice within the classroom should be the director of learning and assessment (Helmane & Briska, 2017; Kaufman, Moss & Osborn, 2003). This approach to teaching and learning necessitates assessment strategies that privilege the student voice and align with futures imagined in policy (ACARA, 2016; DESE, 2016; DESE, 2019; DET, 2017; Lowrie, Downes & Leonard, 2017; OCS, 2013, 2014; QCAA, 2017; Rosicka, 2016). The PCC curriculum innovation achieved this using student interviews, student conferences and project evaluations.

6.3 Synthesis: Middle enactment phase (Years 2-3)

In the second and third years of enactment at PCC, the focus of the STEM Studies subject was on understanding sources of emotionally driven behaviours of students, connecting students with the world beyond the classroom, and working through conflicts that arose. During this enactment phase, students' behaviours within the classroom had emotional drivers in response to the different ways of working in the STEM Studies classroom. Throughout the learning process, students experienced frustrations with the difficulty of open-ended problem-solving. This may have been due to inexperience appropriately framing problems that were based in real-world contexts, a skill that students may rarely have the opportunity to develop within traditional discipline-based classrooms, where curriculum is organised around specific skills and knowledge (Helmane & Briska, 2017; Kaufman, Moss & Osborne, 2003). One strategy that PCC employed was a professional learning conference for students, the "PCC STEM Conference". Years two and three of enactment demanded conflict management strategies within the staff. Ideological conflict arose within the teaching staff in relation to specific activities within the enactment strategy, however, was resolved through communication and mediation. Further conflict arose between teaching and administration staff when teaching staff were withdrawn from a team-teaching environment, and when administration staff introduced external priorities for the STEM Studies course that were misaligned with the ideological positioning of the curriculum innovation.

Critical principles of enactment that emerged within the middle phase of enactment related to emotional responses with the different ways of working, connecting students with the world beyond the classroom, and addressing conflicts. Working in a transdisciplinary environment, students experience a different type of classroom than in discipline-based courses, where learning is organised around questions and concerns that they can pose (Helmane & Briska, 2017; Kaufman, Moss & Osborne, 2003). At PCC, this requirement to develop personalised problems and questions was a source of frustration for students. Enacting a transdisciplinary pedagogy requires teaching staff to be cognisant of the emotional tone of the classroom, and scaffold students to experience success in developing personalised problems. Connecting students beyond the classroom is a factor mentioned in many policy documents (DET, 2017; Education Council, 2015; Lowrie, Downes & Leonard, 2017; OCS, 2013, 2014; QCAA, 2017), and emerged as a principle of enactment at PCC to meet both policy priorities and to assist students to engage in real-world problems. At PCC, this was achieved through an onsite STEM conference, that acted as both a networking opportunity and an ideation catalyst. When conflict emerges within a curriculum innovation, the PCC enactment strategy would suggest that mediation and clear communication of ideological positioning of the enactment strategy can be important mitigating factors.

6.4 Synthesis: Recent enactment phase (Year 4)

The most recent enactment year at the time of research has focussed on distilling what sets STEM Studies at PCC apart from other STEM initiatives. It also included a reflective period, particularly for administration staff, who had begun to feel the emotional weight of the policy imperatives. The PCC enactment strategy can be viewed as leading change in STEM policy enactment, through the pedagogical framework employed by PCC. The pedagogical techniques employed by teaching staff within the PCC curriculum innovation demonstrated a focus on meeting the needs of students participating in the course, and include:

- A responsive pedagogy that flexibly works to suit the needs of the students and their projects
- Exposing students to authentic open-ended problem-solving tasks, precursored by problem framing, that culminate in implementation and evaluation of the student-led project
- Using questioning techniques in the classroom to engage the students in using the 21st century skills for self-identified purposes within their project
- Using scaffolding and empathetic strategies with students who are disengaged from, or feeling frustrated within, the process of reaching solutions to self-identified problems
- Utilising understanding of self, teams and society to solve problems in an authentic manner, related to real-world issues

Critical principles of enactment that emerged within the most recent enactment phase were pedagogical techniques that align with the ideological positioning of the curriculum innovation; and a pedagogical framework that draws on a rich understanding of problem-solving. The Programme for International Student Assessment (PISA) framework for problem solving highlights the cross-disciplinarity of authentic problem solving, defining it as “an individual’s ability to use cognitive processes to confront and resolve real, cross-disciplinary situations where the solution path is not immediately obvious” (Organisation for Economic Co-operation and Development (OECD), 2003, p. 156). As a high-level cognitive skill, “…problem-solving is theorised diversely as a set of general-purpose procedures that can be applied across domains”, a process that is marked by the techniques employed at PCC (Curtis, 2019, p.71). Pedagogical techniques employed within a curriculum innovation should be fit for purpose, suited to the context of a curriculum innovation, with a focus on student empowerment and building student agency. The PCC curriculum innovation achieved this through a responsive pedagogy, student-led projects, questioning techniques to engage students in self-reflection, scaffolding for students who feel frustrated by the process and explicit teaching for understanding of self, teams and society. The PCC curriculum innovation further developed a pedagogical framework that aligned with a policy-driven understanding of STEM education within the school's context (see Figure 7).

6.5 Synthesis: Recent enactment phase: evaluative focus

A reflective and evaluative focus emerged within the most recent enactment phase. Reflection on the enactment journey revealed curriculum structures of the PCC STEM education enactment strategy, personal characteristics of teachers within the curriculum innovation, the specific roles that actors played, character traits and roles that people were required to assume within the enactment strategy as well as the perceived success of the project within the PCC context. Curriculum and classroom structures of the PCC STEM studies subject were revealed throughout evaluative reflections of both teaching and administration staff, including

- Collaboration and team-teaching
- Open-ended problem-solving approach
- Student-centred approach with a specific focus on student agency
- Explicit teaching of thinking skills
- Non-traditional assessment and reporting that have an A-E reporting rubric adapted from 21st century skills (QCAA, 2019)
- An onsite STEM conference to encourage networking and connections with real-world problems
- Cognitive dissonance opportunities

Problem framing, as an explicitly taught step within open-ended problem-solving, was identified as an important structure within the PCC enactment strategy. Whilst problem-framing is not explicitly mentioned in policy, problem-solving usually is (ACARA, 2016; DESE, 2016; DESE, 2019; DET, 2017; Education Council, 2015; Lowrie, Downes & Leonard, 2017; OCS, 2013, 2014; QCAA, 2017; Rosicka, 2016). Problem-framing emerged in response to students feeling frustrated within the middle enactment phase due to an apparent lack of understanding of how to deeply understand problems. Discrete, well-timed cognitive dissonance learning activities where students experience, for example, an incorrect resource or harsh deadline pressures, assist with future problem-framing.

The transdisciplinary pedagogical framework employed within the PCC STEM Studies subject seems to sit in contrast with traditional methods of teaching and learning and also how a traditional teacher is characterised. Policy language about who a STEM teacher is usually relates to specialised qualifications, expertise or experience in one of the STEM umbrella subjects of Science, Technology, Engineering or Mathematics (ACARA, 2016; DET, 2017; Education Council, 2015, 2019; Lowrie, Downes & Leonard, 2017; OCS, 2013, 2014; QCAA, 2017; Rosicka, 2016). This description stands in stark contrast to the way a teacher is characterised within the PCC enactment strategy, which instead describes the values, personal characteristics and ways of working that teachers utilise within the curriculum innovation. Identified by teaching and administration staff, teachers of STEM education at PCC are asked to:

- Be passionate
- Be empathetic
- Be open to trying new things
- Have a growth mindset
- View themselves as learners
- Have the 21st century skills they are trying to build in students

Interview data further revealed that there were mindsets and ways of working that may inhibit transdisciplinary pedagogy, however, the impact of inhibiting actions can be dampened or mitigated when the teaching and learning occurs in a team-teaching environment. Teachers of the STEM education curriculum innovation at PCC are not required to have specific discipline-based qualifications or expertise, but rather, are valued as facilitators of transdisciplinary pedagogical ideologies through their values, personal characteristics and ways of working.

Specific roles that actors hold within the enactment strategy were described throughout evaluative reflection on the most recent phase of enactment. At PCC, the administration perspective of the teacher’s role in STEM enactment is to model the future of work to students, a sentiment that was addressed through strategic curriculum decisions, such as the inclusion of teaming within the pedagogical framework (see Figure 7), and the distinctive assessment design that values the voice of the student. The teaching staff describe the role of a teacher within the PCC

STEM curriculum innovation a facilitator of student-led learning. As a facilitator, the teacher utilises flexible pedagogical techniques that are responsive to the students' needs within lessons or projects. In reality, this can look like explicit instruction of specific skills or knowledge or responding with questioning and scaffolding techniques to facilitate project work. Administration and teaching staff agree that collaboration is an important facet of a transdisciplinary pedagogical framework. Collaboration within the PCC STEM curriculum innovation occurs between teachers to facilitate shared teaching and learning experiences that align with the school's ideological understanding of STEM education, between students to create teams for student-led project work, and between teachers and students to facilitate teacher-led and student-identified learning experiences. On a number of occasions, administration staff were intentionally included with roles the STEM classroom, as student-led projects needing to be implemented on site required a pitch and approval process. Including administration staff in the classroom fostered connections to real-world issues, raised by student questions and concerns about their own educational experience. It also included an unintentional benefit of raising awareness and a deeper understanding of the transdisciplinary pedagogical framework in administration staff, who determine the success of the program.

The perceived success of the PCC STEM curriculum innovation was a focus of reflection within the evaluative phase of enactment. Whilst objective benefits and advantages are not able to be identified within the PCC enactment strategy due to a lack of clear success criteria within published policy (DET, 2020), anecdotal evidence describes the program a "success" from the school's perspective (A1, p. 11). Success in this context is relative, with administration staff describe wanting a "rich experience" for students within the school, and teaching staff describe the program as a "rich experience" for students ((A2, p. 6; T1, p. 9; T2, p. 4). The PCC curriculum innovation was contextually described as successful, as it demonstrated a rich learning experience for the students who studied the program.

Critical principles of enactment identified throughout the evaluative reflection on the most recent enactment phase include explicit teaching of problem-framing as a step within open-ended problem-solving; a focus on the values, personal characteristics and ways of working of teachers enacting the curriculum innovation; consideration of the specific roles that each of the actors hold and descriptions of success. Explicit teaching and use of clear problem-framing is an important step to include in the problem-solving process, to sidestep student feelings of frustration associated with student-led projects. Teachers within a transdisciplinary pedagogical framework can be described as facilitators of learning, with values personal characteristics and ways of working that allow enactment of the contextual ideology of STEM education. The role, then, of each actor within a STEM curriculum innovation can be clearly defined, to ensure appropriate collaboration can occur. When actors understand and implement their roles in full, success can be measured according to criteria that is contextual to the site, until clear success criteria that described STEM education in Australia is made explicit.

6.6 Synthesis: Recent enactment phase: future focus

When looking to the future, STEM Studies at PCC is a valued part of the educational experience for students within the school due to the perceived success of the enactment strategy, however, expansion of the program is described as difficult. Administration staff describe a newly established connection to the emotive drivers of the policy language as felt by teaching staff in the pre-enactment stage. Administration staff, through the reflection on the enactment journey, report now feeling the emotional burden of the policy language and would like to see the STEM curriculum innovation to expand through to college to include more student cohorts. However, the constraints of timetabling, whilst not initially a problem due to a convenient gap, now provide the difficulties in moving forward. If this significant timetabling obstacle were to be overcome, staff also identify that finding staff who embody the values, personal characteristics and ways of working to enact the PCC pedagogical framework may prove difficult. Currently at PCC, teacher training into the STEM studies subject relies heavily on a mentoring relationship and period of observation between current teachers and new teachers.

The concerns for the future raised within the recent enactment phase at PCC suggest two key critical principles of enactment, however, these have both been previously identified within this study. Firstly, timetabling of a novel subject can be a legitimate constraint for enacting or expanding a STEM curriculum innovation, and must be approached with risk management strategies from the organisation and the individual teachers in mind. Secondly, staff who are enacting the STEM curriculum innovation must consider their values, personal characteristics and ways of working as important facets of enactment.

6.7 Summary: Critical principles of enactment identified throughout enactment phases

Implementation of a STEM education subject was approved at PCC due to a research-based proposal, passionate teachers and a convenient gap in the timetable. Throughout the enactment period, a pedagogical framework, key curriculum structures and a description of who a STEM teacher is at PCC have emerged. These examples have been distilled into the following list of critical principles of enactment that emerged within the case study:

- In the development of a STEM curriculum innovation, schools should closely consider STEM education definitions and then align strategic pedagogical and curriculum decisions with an ideological understanding.
- Conflict may arise within a novel curriculum innovation. Clear communication of the ideological definition and purpose of STEM education as well as mediation processes can assist to resolve conflict.
- Logistical constraints such as timetabling and staffing may emerge but can be overcome through the collaborative approach of administration and teaching staff to risk management.
- Staffing decisions for a transdisciplinary STEM curriculum innovation should consider the values, personal characteristics and ways of working. STEM education curriculum innovations should further consider the specific roles that each of the actors hold and determine contextual descriptions of success.
- Curriculum structures of a transdisciplinary STEM prioritise student agency and the development of fit-for-purpose assessment strategies that privilege the student voice.
- Pedagogical techniques should consider a range of emotional responses that students may exhibit in response to different ways of working, and explicit inclusion of connections to the world beyond the classroom.

- Pedagogical techniques selected for use should have foundation in the ideological positioning of the curriculum innovation. This can lead to a pedagogical framework that draws on a rich understanding of problem-solving. Problem-solving in a school context should include explicit teaching of problem-framing.

At PCC, these principles of enactment were identified and demonstrated through the following curriculum structures, pedagogical techniques and staffing characteristics.

- Curriculum Structures:
  - Collaboration and team-teaching
  - Open-ended problem-solving approach
  - Student-centred approach with a specific focus on student agency
  - Explicit teaching of thinking skills
  - Non-traditional assessment strategies that utilise an A-E reporting rubric based on 21st century skills (QCAA, 2018)
  - STEM Conference to encourage networking and connections with real-world problems
  - Discrete cognitive dissonance learning activities
- Pedagogical Framework (see Figure 7):
  - A responsive pedagogy that flexibly acknowledges the needs of students and student-led projects
  - Providing opportunities for students to engage in authentic open-ended problem-solving tasks that culminate in real-world implementation of solutions and evaluation of projects
  - Using questioning techniques in the classroom to engage the students in using the 21st century skills (QCAA, 2019) and general capabilities (ACARA, 2018).
  - Using scaffolding and empathetic strategies to redirect students who are frustrated or disengaged in the classroom
  - Explicitly teaching and providing learning activities that develop an understanding of self, teams and society, in order to develop solutions to problems in an authentic manner

- Teacher characteristics:
    - Passionate about the curriculum innovation
    - Empathetic to students and fellow staff learning new ways of working
    - Open to trying new things and taking pedagogical risks
    - Growth mindset
    - Views themselves as learners
    - Have the 21st century skills (QCAA, 2019) they are trying to build in students

Whilst success criteria for STEM education enactment strategies is yet to be developed by authoritative agencies, the PCC the STEM Studies subject is considered successful within the school's context because it was designed to align with the policy descriptions of STEM education and the college's strategic vision for students. PCC values a "culture of care" where students should feel "…confident and sure that I am loved, valued and safe" (Parklands Christian College, 2022). The curriculum structures, pedagogical framework and teacher characteristics (see Table 34) align with this vision. Alongside the critical principles of enactment identified throughout this case study, curriculum designers in other school settings should ensure that the enactment strategy clearly aligns with that school's context and students. The research, herein, turns to concluding statements that summarise the contributions of case study, address limitations of the research design and suggest avenues for further research.

Chapter 7: Conclusions

Whilst this study was undertaken in the context of a Master of Philosophy research degree, it ultimately began as an impassioned response to the burden of policy descriptions of STEM education in Australia. This study has aimed to explore a descriptive, instrumental case study of STEM education enactment at one independent school in Queensland. The curriculum innovation enacted at Parklands Christian College sought to sincerely align with a policy-informed definition of STEM education. The staff at PCC genuinely sought to provide an educational experience for young Queenslanders that was future-focussed and gave students agency and opportunity to respond to real-world problems. Interrogation of policy descriptions of STEM education in Australia and descriptions of the curriculum innovation through autoethnographic account and semi-structured interviews revealed that a transdisciplinary model of STEM education within curriculum time can be successful within a traditional school setting. This study has further enabled extraction of critical principles of enactment, that could allow this transdisciplinary model of learning to be transferred to other settings, contexts or disciplines.

7.1 Contributions of descriptive, instrumental case study

The findings of the descriptive, instrumental case study are assembled through detailed, in-depth data collection involving multiple sources of information. Throughout the four phases of analysis, findings related to each of the three research questions can be distilled. In the below sections, responses to each of the research questions are detailed, in turn.

7.1.1 Response to Research Question One

Research Question One which states “What are the core constructs of STEM education in Queensland schools as described by national and state education policy?”. This study’s policy analysis revealed important altruistic principles of STEM education for young Australians. STEM education in Australia, as a concept, asks schools to do the impossible: prepare students for an unknown, uncertain and rapidly changing future. Further, teachers are asked to do this with little guidance in regards to what to teach or how to teach it. It seems that what is lacking from policy is both an agreed framework or definition of STEM education and clear, specific enactment advice for schools. This lack of an explicit, unambiguous understanding of what STEM education is and how to enact it can be a source of frustration for teachers, however, it does enable schools to determine their own methods and frameworks for enacting STEM education. At the same time, there is limited guidance for schools to evaluate programs they do enact as there no agreed criteria that schools can use to shape the development of such frameworks.

The language of policies, when interrogated through the theory of interdisciplinary learning (Helmane & Briska, 2017), describes a continuum of approaches from discipline-based to cross-disciplinary frameworks. What is lacking in the language of policy is attention to the intersection between traditional discipline-based knowledge and 21st century skills, particularly when considering teaching and assessment decisions that schools must make. It is this intersection that underpins Helmane and Briska's (2017) conceptualisation of a 'transdisciplinary approach'. Moreover, the language of the policies reviewed highlight the significance of 21st Century Skills (QCAA, 2019) and General Capabilities (ACARA, 2018) such as critical and creative thinking, personal and social skills, collaboration and teamwork. Yet, existing curriculum frameworks provide limited scope to teach or assess these critical principles. For example, whilst the ACARA (2018) Science curriculum includes the Scientific Inquiry Skills strand, connections to the interpersonal and transdisciplinary nature of the 21^{st} century skills (QCAA, 2019) and general capabilities (ACARA, 2018) are not made clear. While at the Federal level, policies such as ACARA (2016), DESE (2019), Education Council (2015), OCE (2013), OCE (2014) and Rosicka (2018) speak to the aspirational inclusion of interpersonal, future-focussed and problem-based structures of STEM enactment, at the Queensland policy level, it is difficult for schools to leverage these ambitions because curriculum frameworks are not yet designed to teach and assess with these principles at the forefront of enactment. Teachers must use these 21^{st} century skills that are desired for students such as critical thinking to notice these gaps and creative thinking to reimagine how STEM education can and/or should be enacted in their context.

The core constructs of STEM education, as characterised in policy, suggest it exists within a continuum of definitions, is authentic and connected to the real world, and has a futuristic view of problem-solving. The findings of this study highlight the need to recognise a transdisciplinary positioning of STEM education and to speak back to policy constructs in ways that identify this conceptual gap in current policy. The PCC curriculum innovation proposes that the ideology of STEM education, as a spectrum of definitions, can be enacted through a transdisciplinary pedagogical framework. The theoretical features of a transdisciplinary pedagogical framework, especially the organisation of curriculum around student questions, concerns and problems (Helmane & Briska, 2017), suggest it is an exemplary approach to enacting the future-focussed policy language. The case study, therefore, provides a unique characterisation of the cross-discipline policy language in action.

7.1.2 Response to Research Question Two

Research Question Two states “How is one example of middle school STEM curriculum conceptualised at one independent school (PCC) in Queensland?”. “STEM Studies”, a subject developed at PCC and enacted as an elective subject with Year 9 and 10 students, was conceptualised as a program that facilitates problem-focussed, student-led projects in response to student-developed questions or concerns. STEM Studies at PCC was implemented because the research-based, policy-aligned curriculum design also demonstrated alignment with the strategic vision and public values of the school. At Parklands Christian College the holistic development of students, who are viewed as uniquely gifted individuals, is a priority. The College professes a culture of care where every member of the community is “a valued part of the Parklands Family” (PCC, 2022). The design of the PCC STEM subject, situated within the school’s strategic vision for students, prioritised the development of students as people who are active and informed citizens of future Australian society.

The overarching design of STEM Studies is to provide support and circumstances for students to respond to real-world problems through a transdisciplinary pedagogical framework. In doing this, there are multiple opportunities for students to develop and use 21st century skills such as critical and creative thinking (QCAA, 2019), but also personal and interpersonal characteristics such as perseverance, grit, persistence, courage, negotiation and teamwork. The STEM Studies subject intentionally avoids explicit instruction of discipline-based skills, knowledge or technology literacy. These are important features of the other, discipline-based classes that students attend at school. However, in the PCC model of STEM education discipline-based knowledge and skills are considered valuable and useful within a problem-framing context. The pedagogy employed at PCC asks that students come to the STEM Studies classroom with the knowledge and skills that they have learned in their other discipline-based classrooms, and put them to use. Further, by esteeming the unique perspective of the world that each individual student brings, and by focussing the group on real-world problems, the PCC STEM subject provides a rare opportunity for students to use their insights and learnings in tangible, meaningful ways. The curriculum and assessment plan developed for the PCC context was deliberately aligned to the policy descriptions of problem-solving in authentic and real-world contexts (ACARA, 2016; DESE, 2016; DESE, 2019; DET, 2017; Lowrie, Downes & Leonard, 2017; OCS, 2013, 2014; QCAA, 2017; Rosicka, 2016). The design of the PCC subject intentionally sought to address a gap in the current policy conceptualisations of STEM education, where transdisciplinary models could provide a springboard towards a consequential shift in education, bigger than just an acronym of four discrete subject areas, deemed to be related.

The enactment of STEM Studies at PCC is the direct result of a real person's emotional response to the onerous burden of policy language, calling on teachers of STEM education to prepare students for an unknown future (ACARA, 2016; DESE, 2016; DESE, 2019; DET, 2017; Lowrie, Downes & Leonard, 2017; OCS, 2013, 2014; QCAA, 2017; Rosicka, 2016). The charge of preparing young people for an unknown future is an abstract and intimidating concept that takes courage to respond to, as it can be difficult and frustrating to know where to begin. Teaching staff at PCC questioned how it is possible to future-proof an educational experience for students in the midst of rapid social and technological development. Further questions arose when considering an education system focussed on delivering academic curriculum organised around knowledge within discrete disciplines. Where, within the current system, can students develop the 21st century skills that value the human experience of working and thinking across disciplines to frame and solve problems? The PCC STEM enactment strategy presents a case of developing students, fundamentally and holistically, as people. It centres on futures-focussed capabilities, such as resilience and adaptability, by releasing students from the pressure to produce responses to teacher-directed tasks, and instead asking them to look within themselves for innovation, creativity, questions, courage and grit. Further, it genuinely strives to develop the ability of students to understand the perspectives of others, to collaborate effectively and ensure solutions are ethical, inclusive, and consider diversity.

The PCC enactment strategy ventured to create a protected space that was interesting to students and impactful on the way they approach all aspects of education, with a view to preparing them with functional and adaptable skills for life beyond the STEM Studies classroom. When considering preparing students for an unknown future, without the assistance of specific implementation advice, PCC chose to focus on the students themselves. The personal and interpersonal skills students have the opportunity to develop through the learning experiences are portable and transferable – students can take their thinking with them into any future. PCC’s ideological approach to STEM education suggests that when technological progressions such as automation or artificial intelligence experience a rise in workplaces and community settings of the future, so, too, should human understandings, presence, and influence over the direction of such developments. At PCC the complexities of being a human including, for example, ethical understandings of technology advancements and how they impact on the lives of people, are regarded as more important than learning how to build a robot or use a drone to complete an in-class task. To function within a classroom environment that values these future-focussed capabilities, teaching strategies – and the teachers who use them – must look different to traditional teaching. To enact this ideological position of futures-focussed STEM education for the whole person, the PCC enactment strategy needed a team of teachers aligned with this position, to drive and implement the subject with middle school students. Using this position of STEM education, the team of teachers purpose-built a curriculum and assessment plan.

Details of the curriculum plan used at PCC can be seen in Appendix 8, as an excerpt of the school's STEM Studies work program. Within the work program, explanation of the pedagogical framework developed at PCC is clearly outlined. At PCC, STEM Studies is considered a transdisciplinary enactment of STEM, that prioritises student-led problem framing and solving in relevant, authentic contexts. Terminology such as 'relevant' or 'authentic' is often used in policy language (ACARA, 2016; DESE, 2016; DESE, 2019; DET, 2017; Lowrie, Downes & Leonard, 2017; OCS, 2013, 2014; QCAA, 2017; Rosicka, 2016), but may seem arbitrary – for instance, what does 'authentic' mean within a classroom? At PCC, the words relevant, authentic and contextual refer directly to a students' experiences of the world around them. When developing projects focussed on student-led problems, questions or concerns, teachers use questioning techniques to draw out how this is a problem the students have personal experience with, or how they came to their understanding of it. Relevant and authentic problem-solving in a Year 9 or Year 10 context must focus on problems that are personally experienced by students or observed problems to which students feel they can bring a unique perspective; that is, of being a teenage student in a small, independent Queensland secondary school. Using problems, questions or concerns that students have noticed in the world around them; students design, manage and enact projects using discipline-based knowledge and skills they have learned in other subjects, or can seek from people they have contact with. People they have contact with can include the teacher-facilitators in the room, or they are free to contact any expert they need. For example, a student requiring assistance with a skill that the team of STEM teachers cannot help with could seek assistance from another teacher or staff member in the school, they could identify a self-education program that will teach them how to do this, or they could contact an expert external to the school and set up a virtual or onsite meeting. The curriculum plan developed by PCC is an attempt to allow students to respond to relevant and authentic problems, drawing on discipline-based knowledge, skills or expertise as required.

The PCC STEM Studies pedagogical framework explicitly includes an exploration of self and society, as well as a focus on teaming. Interpersonal growth is a strong focus of the course, with many activities planned around developing these skills in students. Activities such as MBTI testing (Myers, 1962) allow students to develop a working understanding of their natural tendencies and preferences when working in teams. Results of MBTI tests (Myers, 1962) are then used to form diverse teams within a class, or to allow students to choose roles within a group to which they are suited. Teaming is a recurring focus, approached in a range of ways to demonstrate the benefits of diversity within groups, for students who often prefer to choose teams based on friendships. For example, “The Teacher Project”, listed as the Term 3 project for Year 9 students is a whole class project, where students to apply to work within a team to which they feel best suited. Whereas, “The Two Week project”, listed for Term 1 of Year 10, asks students to form groups to work on a problem for two weeks, before reforming into new groups to continue working on the same problem. During “Student Choice projects” (as occurring, for example, in Term 3 of Year 10), students have full autonomy over the way groups are selected. There is freedom over how many students will work together in a group, how groups are chosen and even how they are managed throughout a project. Students are free to leave and join groups as required. Experience at selecting and working within effective teams to achieve a shared outcome draws student attention to the need for diverse skills sets in a team and to also recognising and developing the skills they, themselves, bring to a team project. Such opportunities are critical to developing 21st century skills purported as significant in the curriculum plan.

After exploration of relevant and authentic problems using 21st century skills, and an understanding of self, society and teams, students arrive at the need to frame and solve problems. Problem-framing may often be overlooked, as it is not explicitly named as a part of the problem-solving focus of policy documents. However, at Parklands, framing a problem appropriately to the scope, scale and perspective of the user is an imperative part of the process. Solutions to problems that have been framed accurately and specifically can often emerge organically. Problem-framing within STEM Studies at PCC takes the form of iterative cycles of investigating, manipulating, designing, and modelling. This process is fluid and provides students with a range of opportunities to develop specific skills in research, data collection, data analysis, prototyping, testing, and implementing solutions. There is also opportunity for students to respond to the implicit challenges of justifying a choice or position with evidence and pushing through when they encounter barriers to progress. In STEM Studies at PCC, “hitting the wall” is a colloquial term that is used with students, to describe these barriers, including the emotional frustration that is often experienced when they are unsure of what to do next. ‘Hitting the wall’ presents a challenge for both student and teacher, as teachers often feel an obligation to provide the next step, and students often look to the teacher for this. This emotion-filled moment is an incredible opportunity to develop authentic resilience and determination, as students learn how to find help when stuck, or unearth their next level of creativity and innovation, without the teacher explicitly telling them what to do. This approach provides a way of facilitating the development of personal and social skills such as resilience and management of self, as suggested by QCAA’s (2017a) explanation of skills associated with the 21st century skills. The iterative process of investigating, manipulating, designing, and modelling provides the framework for framing and addressing authentic problems in STEM, in ways that provide opportunities for students to develop personal and social skills.

Three assessment styles are used in STEM Studies at PCC, an example assessment item can be seen in Appendix 9. Assessment styles were developed to reflect common workplace practices, to ensure that the projects students enact proceed in a manner they may encounter in their future workplaces, regardless of the industry. PCC uses ‘student conferences’ as a formative assessment item, where groups of students present project progress and ask their peers for critical feedback. This assessment technique was designed to mirror common workplace practices such as collaborative team meetings, pitching or project presentations. Through this task, students are provided with an opportunity to practise communicating clearly in written and oral contexts, pitching an idea to an audience of peers, actively listening, questioning and providing implementable feedback. In addition to these obvious opportunities are implicit challenges such as overcoming fears, having difficult conversations, delegating tasks, taking the lead or learning to follow directions, amongst other things. In this way, the approach to assessment in the PCC Stem Studies case provides opportunities for 21st century skills (QCAA, 2019) such as communication, collaboration and teamwork, personal and social skills.

PCC uses two summative assessment techniques, ‘student interviews’ and ‘project evaluations’. Student interviews are a unique style of assessment that may be rare in an educational setting but are common in workplaces in the form of performance reviews. Within this task, students are asked to grade themselves against set criteria (see Appendix 9 marking rubric) and provide evidence or justification of the grade they have awarded themselves. Then, students are asked to meet one-on-one with their teacher to discuss their progress throughout the term and agree on an overall grade for their performance. Within this task, students are given the opportunity to practise reflecting thoughtfully on their performance, truthfully identifying strengths and challenges to their progress and providing evidence of work that may not have been obvious to the teacher. Along with these opportunities are implicit challenges for students to respond to, such as learning to advocate for themselves without over- or under-selling, battling nerves that can accompany performance reviews, and speaking openly with a manager-type person. Project evaluation tasks, such as the example task in Appendix 9, have obvious alignment to workplace practices of report writing and project evaluation. Project evaluations provide opportunities for students to develop a comprehensive written evaluation of their project against set success criteria. There are also implicit challenges for students such as meeting strict deadlines, developing and meeting reasonable success criteria, and writing in an evaluative genre. The three assessment styles utilised within the PCC enactment strategy were purposely designed to give students opportunity to develop skills and ways of working that are common in workplaces, regardless of industry. Through these two summative assessment styles, students are given the opportunity to develop and demonstrate key 21st century skills: critical and creative thinking, communication, collaboration and teamwork, ethical understandings, personal and social skills and information & communication technology skills (ACARA, 2018; QCAA, 2019).

STEM Studies at PCC has culminated in the development of a transdisciplinary pedagogical framework, presented in Figure 7. This unique pedagogical framework first recognises the importance of deep understandings that are taught in discrete subject disciplines and views them as foundational knowledge and skills that students bring to the classroom from other subjects. However, these understandings are only the beginning of the open-ended problem-solving process, which must begin with relevant, authentic and contextual problems, based on student identified questions and concerns (Helmane & Briska, 2017; Kaufman, Moss & Osborne, 2003). The framework then asks the teaching and learning experiences to draw on the 21st Century Skills (QCAA, 2019, p. 2) and General Capabilities (ACARA, 2018), as the vehicles through which students explore their questions and concerns. Elaborating on these skills includes explicit exploration of self, teams and society, to ensure that students are addressing authentic, real-world issues in collaborative ways. Problem framing then allows solutions to problems to reveal themselves, as students are asked to engage in iterative cycles that may include investigating problems, manipulating prototypes or ideas, designing solutions using data collection and modelling. By working through this cyclical process over a two-year period, students of STEM Studies at PCC are developing transcendental interpersonal skills, that will prepare them to be functional in workplaces of the future, regardless of industry.

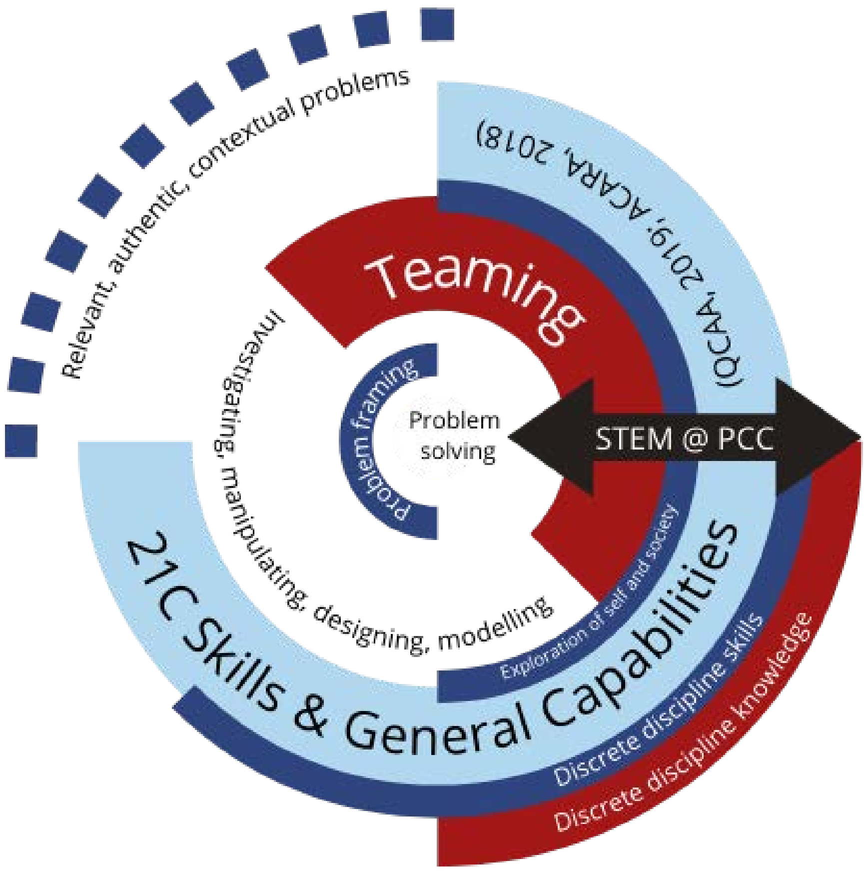

Figure 7. *Pedagogical framework underpinning STEM Studies at PCC*

The graphical representation of the pedagogical framework presented in Figure 7 demonstrates a spiralled, layered approach that the PCC curriculum innovation takes to enacting STEM education. The figure is designed to be read from the outermost layers first, circling inwards as aspects of the framework, in increasing complexities, are drawn into the process. The outer layers of the model represent the discrete discipline knowledge and skills are taught outside the STEM Studies classroom. The relevant, authentic and contextual problems, represented by individual boxes, also begin outside of the STEM Studies classroom, but are quickly drawn into the process, as students seek them out through their lived experiences and learnings. As previously discussed, teachers then build structure to the course from policy and advice documentation and iterative cycles of investigation, modelling, problem-framing and finally problem-solving can occur. The black, multidirectional arrow signifies that at any point in the spiral, the process can change direction, regress, jump ahead or revisit a layer.

The PCC approach to STEM education presents a pedagogical framework that was not seen in the case studies reviewed within this research. The reviewed case studies usually presented an interpretation of STEM education as a collection of practices or activities designed to enhance discrete areas within a discipline-based version of STEM education. The PCC model of STEM education does not endeavour to devalue the importance of activities, discipline-based knowledge, understandings and skills, nor the role technology can play in STEM Education. However, the PCC model would suggest that current trends of technology-focussed activities are selling STEM education far short of what could be possible. A transdisciplinary model of enactment provides opportunities to develop students principally as people, to arm them with transferrable capabilities and the confidence that they will prosper in unchartered futures.

To summarise Research Question Two, the establishment of the STEM Studies subject at PCC was dependent on a school that was willing to take a risk on a research-based project designed by passionate, courageous teachers that aligned with the school’s strategic vision for a student in their context. STEM education at PCC presents an example of how transdisciplinary learning styles are possible within the current educational structures in Queensland, and the holistic impact it can have on the personal and interpersonal development of students, in preparation for unknown futures. This one example of middle school STEM curriculum is characterised by the curriculum structures, pedagogical techniques and staff characteristics that facilitate a transdisciplinary pedagogical framework for enactment. This case, in all its human-centered complexities, presents a new possibility of what a meaningful and intentional education for the active and informed citizens of future Australian can look like.

7.1.3 Response to Research Question Three

Research Question Three asks “What are the critical principles of enactment to enable PCC STEM curriculum to be transferred to another setting?”. Three critical principles of enactment were identified throughout this study, that would allow the PCC STEM curriculum innovation to be transferred to another setting: (1) school system structures that facilitate the contextual curriculum design that is aligned to policy language; (2) creative human resourcing and (3) the character profile of the teachers involved in enacting the curriculum design.

The first critical principle of enactment to consider is the school system structures of the PCC enactment strategy. Structures that facilitated the enactment of a transdisciplinary, policy-aligned curriculum design of STEM education at PCC included a curriculum with a low resource model, a convenient gap in the timetable and pedagogical framework grounded in student agency and interpersonal 21st century skills. At PCC, teachers acting as curriculum leaders proposed the STEM Studies subject to administration staff and were able to demonstrate, through evidence, how the transdisciplinary curriculum innovation aligned with the policy language. The evidence base that was gathered before enactment included a review of policy documentation, analysis of how common understandings of STEM education seemed to misalign with the aspirational principles of policy language, and anecdotal evidence gathered when visiting schools similar to PCC that were also enacting STEM in their locations. This evidence base, along with the willingness of the administration staff to take and manage the risk of enacting a novel curriculum design, led to approval to implement. After approval was granted, the structures that facilitated enactment of the STEM Studies curriculum framework included a low resource model and a convenient gap in the timetable. The pedagogical framework developed at PCC can be understood through a description of the pedagogical techniques, curriculum structures, and teacher characteristics that were identified as important aspects of the PCC curriculum innovation strategy, outlined below in Table 34.

Table 34.

Conceptualisation of the PCC STEM education enactment strategy

STEM Studies at Parklands Christian College		
Curriculum structures	**Pedagogical Techniques**	**Teacher characteristics**
- Open-ended problem-solving approach - Student-centred approach with a specific focus on student agency - Explicit teaching of thinking skills - Non-traditional assessment strategies that mirror common workplace assessments - Assessment rubric based on 21st century skills (QCAA, 2019, p. 2) - STEM Conference to encourage networking and connections with real-world problems	- A responsive pedagogy that flexibly works to suit the needs of the students and their projects - Open-ended problem-solving tasks that privilege implementation over assessment - Questioning techniques that point to 21st century skills (QCAA, 2019) - Scaffolding and empathetic strategies for students who are disengaged with the process - Gaining and utilising an understanding of self, teams and society	- Passionate - Empathetic - Open to trying new things - Growth mindset - Views themselves as lifelong learners - Possess the 21st century skills (QCAA, 2019) that they are trying to build in students

At PCC, the STEM Studies subject was initially approved as it provided a solution to a convenient gap in the timetable, and because the curriculum design did not require an initial financial outlay for physical resources. The PCC curriculum design privileged interpersonal 21st century skills (QCAA, 2019) and the framing and addressing of problems in authentic ways. This approach to teaching STEM education in the Australian context presents a student-focussed transdisciplinary model of teaching and learning.

The second critical principle of enactment to consider is the human resourcing of the PCC enactment strategy. Whilst the PCC enactment strategy recognises that technology has the potential to play an integral role in problem-solving processes, the PCC curriculum design did not use technology-based activities as the primary catalyst of learning experiences. Instead, the pedagogical techniques selected for use were driven by theories of transdisciplinary instruction of STEM education (Helmane & Briska, 2017), with a strong focus on student questions and 21st century interpersonal and thinking skills. Selection of pedagogical techniques such as open-ended problem-solving organised around student questions took priority over explicit instruction of discipline-based skills which occurs in other discipline-based subjects. Curriculum structures of transdisciplinary STEM education prioritise student agency and the development of assessment strategies that privilege the student voice. Staff selected teaching and learning strategies that considered the emotional responses of students to new and different ways of working and provide clear connections to life beyond the classroom.

Although there was not an initial financial outlay for physical resources, human resourcing meant that the enactment of STEM Studies at PCC did attract a cost. Team teaching was viewed as critical by teaching staff, to ensure students had access to facilitators with different areas of expertise, knowledge bases, skill sets, teaching styles and personalities. Transdisciplinary enactment strategies, according to Helmane and Briska (2017) develop curriculum in response to student questions and concerns, utilising knowledge and skills from multiple disciplines. PCC facilitated the utilisation of knowledge and skills from multiple disciplines by allowing two teachers from different disciplines, in this case the Head of Faculty (Mathematics and Science) and the Head of Faculty (Design & Technologies) to team teach. Moreover, the critical nature of team teaching to transdisciplinary enactment strategies was highlighted in the ideological conflict arose when teachers were divided between classes. A divergence in the way the programs were constructed and delivered in Year 9 and Year 10 emerged, when teachers delivered courses in a single teacher setting. Human resourcing, and in particular the areas of expertise, knowledge bases, skill sets, teaching styles and personalities that come with team teaching, is a critical principle to consider when enacting transdisciplinary STEM curriculum. When making staffing decisions for transdisciplinary initiatives such at the STEM Studies at PCC case, school leaders should consider team teaching environments, and invite teachers who express a willingness to work collaboratively, an openness to innovate and take risks to participate.

The third and final critical principle of enactment to consider is the character profile of the teachers involved in enacting the curriculum design. At PCC, STEM teachers were characterised as inquisitive; view themselves as a learner; having the ability to act responsively to situations and student needs that arise in the classroom; are patient and empathetic in the classroom; and, demonstrate the same 21st century skills that are being developed in students. In essence, this can be distilled to working responsively with a facilitator mindset, with a focus on student agency and creating and responding to authentic opportunities to support students to learn and develop 21st century skills. STEM Studies teachers at PCC were described by administration staff as passionate, well-informed, critical, creative and innovative. Administration staff at PCC also noted that when faced with very different ways of working in the classroom, STEM Studies teachers needed to be courageous in risk-taking. Teaching staff of transdisciplinary curriculum must be willing to work outside the normal constructs of a classroom, including relinquishing a traditional view of teachers as experts; imparting knowledge and skills to students. When transdisciplinary curriculum is organised around students' questions (Helmane & Briska, 2017), the learning environment must be overtly student-focussed with teachers working to facilitate learning. The case presented, herein, of enactment of STEM Studies at PCC, presents a student-focussed, transdisciplinary learning experience. Staff, then, are invited to teach using this approach. Those involved were selected because they expressed a willingness to operate in an environment where the student voice is actively prioritised.

At PCC, STEM education was enacted through a research-based program that could demonstrate alignment with policy descriptions of STEM education in addition to being tailored to the school's strategic vision for who a PCC student is. Approval to implement the STEM Studies subject as an elective with Year 9 and Year 10 students was given when a gap in the timetable arose and the curriculum design didn't require an initial financial outlay for resources. Arguably, the most critical principle of enactment of STEM studies at PCC is that of the willingness of the teachers to collaborate on curriculum design and delivery, and to facilitate student-centred learning within a transdisciplinary pedagogical model. Staffing decisions for a transdisciplinary STEM curriculum innovation should be made in close consultation with teachers. Open dialogue about the significant shift in practice from discipline-based, teacher-centred pedagogies to a student-centred, transdisciplinary approach is critical to ensuring that the teachers are willing to commit to working in a way that will demand a shift in the approach and challenge them to become learners in their classrooms, alongside their students. In addition, discussions about the significant shift toward developing personal and interpersonal skills requires teacher to feel prepared to have difficult, emotion-charged behaviours with students, and this may require additional professional development for staff. .

7.1.4 Summary of Responses to Research Questions

In summary, this descriptive, instrumental case study presents one example of middle school STEM curriculum enactment informed by current Australian STEM education policy. The case study highlights gaps in current conceptualisations and enactments of STEM education and, through analysis of the case, a unique pedagogical framework for STEM Education alongside critical principles of enactment were distilled, both of which can be utilised to transfer the STEM Studies at PCC approach to other school settings in Queensland.

Current policy does not explicitly explain how to enact STEM education. Instead, the suite of policies analysed describe numerous possibilities for the enactment of STEM education: from discipline-based approaches to cross-curriculum approaches that draw on connections to real-world and the future, with a focus on authentic problem-solving. Review of current cases of STEM enactment highlighted that most documented cases in Queensland are technology-based, occur in primary school settings and often in extra-curricular time. The STEM Studies at

PCC case extends on the existing literature and policy descriptions of STEM Education by conceptualising a transdisciplinary STEM pedagogy enacted within curriculum-time in secondary school. The PCC model of STEM education does not devalue the significance of discipline-based knowledge and skills, but rather aims to provide circumstances in which students can springboard these understandings to make a tangible difference, and to develop their own personal and interpersonal characteristics. The pedagogical approach taken in the STEM Studies at PCC case, earnestly aims to prepare students for unknown futures. STEM Studies at PCC uses a student-centred pedagogy that incorporates multiple entry opportunities for students to learn and develop 21st century skills through exposure to authentic problem-framing and problem-solving opportunities. STEM Studies at PCC is a curriculum innovation that utilises a unique transdisciplinary pedagogical framework and a strong focus on interpersonal 21st century skills. In STEM at PCC, student voice and agency are an active priority, and teachers facilitate learning through collaborative teaching and assessment aligned with authentic work-place oriented processes and tasks. Students of STEM Studies at PCC leave the two-year course having experienced a rare opportunity for holistic personal growth, discernible impact on the world around them and skills to adapt to unknown futures. The sum of these experiences aims to develop students' courage to innovate, self-confidence in their important perspective of the world and the understanding that they can make a difference, beyond the four walls of a Science, Technology, Engineering or Mathematics classroom.

7.2 Limitations of descriptive, instrumental case study

Despite the advantages of qualitative analysis providing depth, detail, and textural richness of insight into a phenomenon being studied, there are a range of limitations associated with this study (Yin, 2003). The design of the research as a case study comes with inherent limitations due to the data collection methods selected. This includes limitations such as response bias and inaccuracies due to recall when using interview methods, selectivity and bias due to participant observer's manipulation of events (Yin, 2003). Therefore, the researcher's involvement as a member of the teaching staff within the enactment strategy must be noted. Further, due to limited scope and scale associated with a Master of

Philosophy research project, perspectives of other parties involved in the curriculum enactment, most notably students and their families, were not considered in the final study. Initial study designs did include seeking student perspectives, however, due to COVID-19, the study design had to be revised to remove interactions with students. Future research should include these important perspectives, particularly when looking to evaluate the relative success of the program.

7.3 Recommendations for future studies

- The scope of this case study is limited, as it exists within one independent school in Queensland and was conducted under a Master of Philosophy program with limited scope and scale. The key findings from the STEM Studies at PCC case highlighted the following areas for further research: A scoping review to identify criteria that could be used to objectively evaluate a STEM education program. PCC describes their program as successful, however this success is limited to the perspectives of the administration and teaching staff involved within the project.
- Student and parent perspectives were not considered in this study. These perspectives represent important voices in this space, but the scope of this study, and revisions made to contend with COVID-19 lockdowns, limited it to perspectives from school staff. Future research should include these perspectives, particularly in relation to evaluating the success of the program from the student perspective.
- Teacher preparation for working within a transdisciplinary pedagogical framework was not considered in this study. Research is needed to understand the extent to which both preservice and in-service teachers are exposed to transdisciplinary pedagogical frameworks through either initial teacher education and/or ongoing professional learning, and to identify best practice principles for enacting such a framework to support student learning in classroom contexts.
- Transdisciplinary learning may not need to be limited to STEM education. When policy language asks STEM teachers to be innovative in teaching, could a transdisciplinary model of STEM education provide progressive

leadership in education, designed to better serve 21st century learners and future Australian society?

7.4 Concluding remarks

Discrete learning areas, deep understandings and subject-specific skills are important factors that contribute towards Australia's STEM-based future. However, alongside a discipline-based understanding of STEM in Australia, this example of middle school STEM education presents a case for using transdisciplinary methods of teaching and learning. The PCC curriculum innovation demonstrates that working in a transdisciplinary pedagogical framework, where student questions and concerns drive a rich and authentic problem-solving environment, speaks directly to the purpose of STEM education articulated in national policy (Department of Education, Skills and Employment, 2019; Education Council, 2015, 2019; OCS, 2013, 2014). Without actionable implementation advice but with strong emotional motivation, PCC set out to sincerely address STEM education policy imperatives. The PCC enactment strategy showcases what thoughtful, passionate, empathetic and courageous educators can do when supported and encouraged to innovate and take risks. STEM Studies at PCC is a curriculum innovation that genuinely set out to prepare young Australian students for an unexplored future. The curriculum designed at PCC intentionally avoids the bequeathing of discipline bound knowledge and skills from teacher to student, and focusses on developing students to be able to adapt and respond with courage, confidence, perseverance and grit. It utilises a student-centred pedagogy that incorporates opportunities to learn and develop personal and interpersonal 21st century skills through exposure to authentic problem-framing and problem-solving opportunities.

The STEM Studies curriculum innovation has been successful at PCC because it aligns with the school's culture of care for the individual and aligns with the strategic vision of holistic personal growth in students. This case demonstrates that it is possible to implement a transdisciplinary approach to learning within a traditional schooling environment; and it has the potential to be transferred to other settings or contexts. However, the STEM Studies at PCC case highlights that preparing students for an unknown future must be anchored in development of the whole person – with an emphasis on personal and interpersonal characteristics such as problem-framing, collaboration, communication, ethical decision-making, resilience, and persistence to find solutions even when faced with difficult and messy problems. In this light, STEM education could become less about robots, drones, and coding and more about how young people can learn to think and respond when faced with the advertised complex, multi-disciplinary and multi-dimensional challenges of the future. STEM education, focused on personal and interpersonal skills, can support people to work together to realise their preferred, shared, future.

Appendix 1 – Full search terms log

Research Question One: Policy Analysis

What are the core constructs of STEM education in Queensland Schools, as described by state and national agendas?

Keywords:

Core constructs*, STEM, education*, Queensland, state*, national*, agenda*.

***Synonyms:**

Core - essential, fundamental, imperative, crucial

Constructs - components, elements, factors, framework

Education - teaching, programs, learning

State / National - government, governmental, federal, authority

Agenda - policy, policies, guidelines

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Search Reference	Search term	AND/OR	Search term	AND/OR	Search term	Results
1a	STEM	AND	Queensland	AND	Education	649
1b	STEM	AND	Queensland	AND	Education OR Teaching OR Programs OR Learning	442
2a	STEM	AND	Queensland	AND	Agenda	186
2b	STEM	AND	Queensland	AND	Agenda OR Policy OR Policies OR Guidelines	472

3a	STEM	AND	Queensland	AND	State OR National	589
3b	STEM	AND	Queensland	AND	State OR National OR Government OR Governmental OR Authority OR Federal	604
4a	STEM	AND	Queensland	AND	Core Constructs OR Core elements OR Core components OR Core Factors OR Framework	268
4b	STEM	AND	Queensland	AND	Essential Constructs OR Essential elements OR Essential components OR Essential Factors OR Framework	414
4c	STEM	AND	Queensland	AND	Crucial Constructs OR Crucial elements OR Crucial components OR	172

					Crucial Factors OR Framework	

Research Question Three: STEM enactment advice Which principles of enactment are critical to consider if the PCC STEM program were to be transferred to another school setting?
Keywords: STEM, program*, principles of enactment*, PCC [Queensland]
Synonyms: Program – initiative Principles of enactment – enactment
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Search Reference	Search term	AND/OR	Search term	AND/OR	Search term	Results
5a	STEM AND Queensland	AND	Program	AND	Principles of enactment	29
5b	STEM AND Queensland	AND	Program	AND	implementation	241
6a	STEM AND Queensland	AND	Initiative	AND	Principles of enactment	12
6b	STEM AND Queensland	AND	Initiative	AND	implementation	140

Appendix 2 – Analytic Memos: Autoethnography data

Secondary code	Tertiary codes	Reference & Memos	Direct quote
Goal oriented behaviours, acts or activities	A - Negotiating		**Negotiating the types of problems that were acceptable for students to address in the 10 STEM program. This links to how ADMINISTRATION STAFF describes this from an Admin perspective:** **Early implementation phase:** "… We were noticing that students kept wanting to solve school based problems like litter or uniforms, and weren't thinking beyond the classroom. I really felt that this was due to their socialisation into assessment responses in schools - they hadn't yet grasped the idea that they had free and unlimited choice." (Entry D, 2021)
	B - Blaming		
	C - Leading		**Pre-enactment / inspirations :** "… I committed to answering the question for myself, WHAT IS STEM? I started… reading everything I could find related to STEM in Australia. I felt convicted by the Office of the Chief Scientist and Education Council publications in particular, as they felt like authoritative voices" (Entry B, 2021) **"…**it was a good representation of what STEM should be, as it focussed on thinking skills. Hearing a keynote speaker… [speaking] about futuristic knowledge economies [and the] need for students with thinking skills. This was really when I started to ideate." (Entry B, 2021) **"…i**nspired by future thinking skills, changing educational paradigms, and good some examples of STEM. After reading and writing, I felt like I had a good idea going forward. I wanted to implement a new type of elective subject with our Year 10 students." (Entry B, 2021) **Onboarding new teachers:** "… [the] priorities were to 1) get T2 to understand the heart of why [teacher] designed the program this way (in response to enacting

			policy rather than implementing curriculum); 2) allow T2 time to watch and integrate into the unique ways of working (transdisciplinary meaning organically seeking/learning/using discipline based knowledge and skills to actively solve a contextual problem) and increase T2's confidence in being able to teach within this different pedagogy." (Entry J, 2021)
	A - Complaining		
Emotion oriented behaviours, acts or activities	B - Compensating		
	C - Watchful	A2, p. 7 A1, p. 6 **Administration seem to be aware of policy imperatives such as workforces of the future, yet don't specifically refer to the policy documentation.** **We started with the oldest students available to us under the less prescriptive Australian Curriculum. I wonder what would have happened if we started with Year 7s instead – would have been "less risk" I think. The way we have enacted has really been a backwards mapping approach – start with the end goal in mind**	**Considering what STEM is:** - **Pre-enactment** "When I considered some of the projects that people were presenting as STEM (E.g., the UQ Sunflower growing competition), I wondered "Where's the Maths in that?" (Entry A, 2021) - **Future of STEM at PCC** "We discussed why STEM is important, and that it's a clear national priority and policy directive, without curriculum guidance for schools. We discussed a revamp and expansion of the current STEM program - into earlier years of high school" (Entry H, 2021) **Reflecting on student behaviours:** - **General frustration:** "Sometimes the students feel frustrated with the process" (Entry N, 2021) - **Year 4 (recent)** "…they are still coming into the elective subject with closed mindsets and wanting teacher guidance." ***This links to future considerations of where STEM at PCC needs to go next. Suggestions from Admin were focused around moving it into earlier years of high school.*** "…the 10 STEM students still seem very limited in their thinking - even though the majority of them have been through the 9 STEM program. The 9 STEM program seems to be a bit too disjointed, without a resolution or flow to the discrete projects they have been completing" (Entry K, 2021) ***This links to Structures/B evolution of pedagogical strategies*** ***In reference to the Year 9 program, [teacher] reflects that*** "they haven't yet developed the ability to release their minds to dream bigger. It still felt like they were trying to produce work that would

		and then work backwards when we find gaps in the students' skills, thinking skills, knowledges, ways of working, etc. Link this to A1's suggestion of going to Prep/Year 1 next (located in Constraints/A)– filling in the end and the beginning first. Like doing the edges of a puzzle first?	please the teacher, rather than creatively reacting to problems" (Entry K, 2021) **[TEACHER], reflecting on a particularly inspirational lesson in Term 4 of Year 10 STEM, describes a range of student behaviours as** "such an inspirational lesson with the students" (Entry M, 2021). **The behaviours can be classified as working well as a team, working to the students' strengths, learning new skills that they discovered were needed and a significant behavioural difference from other classes.** "It's incredible to see them finally enacting all the teaming, interpersonal intelligence, clear communication, support for others and iterative innovation that we have been working them towards throughout the year" (Entry M, 2021) "The way Student A acts in Maths is so different to the way s/he acts in STEM. In Maths s/he avoids work and disrupts others by getting out of his seat, playing videos on his phone loudly or talking and distracting others. S/he can be confrontational when her/his behaviour is addressed. In STEM, s/he is a natural leader. S/he is consistently on task and does her/his best to keep the rest of her/his group on task as well. Her/His project is innovative and well researched. S/he rarely plays on his phone" (Entry M, 2021)
	D - Worrying		**Expressing feelings of anxiety or concern about:** - **Importance of STEM education** "feeling really intimidated by everyone telling me how important STEM is." (Entry A, 2021) "I left that 2015 conference with a strong sense of guilt that we weren't doing STEM at our school" (Entry A, 2021) "T1 is starting to realise the importance of STEM education, and feels the guilt of inaction when confronted with policy imperatives" (Entry H, 2021)
	E - Fighting		**Early year sources of conflict. Iron sharpens iron or hinderance to the evolution of the program?** - **STEM Conference** "… after…programming expanded, T1 felt that it didn't meet its goal anymore. I completely disagreed with T1 on that and felt that the

			increased student to student networking opportunities was a major bonus to what we wanted our students to achieve." (Entry F, 2021) - **Mission drift** "The next instance of conflict came about slowly, through a process of mission drift." (Entry F, 2021) "In 2019, the STEM program was extended to Year 9, and the teaching responsibilities were divided. Up until this point… [it was] team-teaching one class in one room. In 2019, T1 took over the Year 9 program, and [TEACHER] continued to refine the Year 10 program." (Entry F, 2021) "… there was further mission drift between the STEM teachers and the Administration. Administration asked that we make STEM a "Pre-Engineering" course, with a focus on leading students into the Year 11-12 Engineering course. This was in direct conflict with the heart of the program, which was focussed on problem-solving and soft skills that students can then take into ANY course, academic or otherwise, that they complete in Year 11-12" (Entry F, 2021)
Rules	A - Timetabling		
	B - Curriculum		
	C - Purpose of curriculum		
	D - Purpose of education		
	E - Purpose of STEM education		
Structures	A – Timetabling and resources		
	B – Curriculum and pedagogy		**Evolution of assessment strategy:** - **Year 1: Non-traditional assessment, no A-E grades reported** "…we wanted to give them the freedom to respond to problems in authentic, meaningful and tangible ways, without the restrictions of "what would my teacher want me to write"". (Entry C, 2021) "This was a really valuable learning experience as it allowed us to refine how to speak to students about what they should do, what to place emphasis on and how to complete a task, when there weren't clear criteria (as there often isn't in life)" (Entry C, 2021)

			"Assessment at this stage was made up of self-reflection tools used at a number of times throughout the year - sometimes it took the form of student conferences (presenting to the class in exchange for feedback) or one-to-one interviews with the teaching panel" "… we did not provide an A-E grade. There was a comment associated with the class, however, that had an explanation of why there was no A-E grade." (Entry C, 2021) - **Year 2: Non-traditional assessment in Year 2, A-E grades instated** "…the decision was made that we needed to provide an A-E grade for students. This was for 2 main reasons: the leadership team decided that there needed to be an A-E grade for every subject. Secondly, there was discussion in the wider cohort that STEM was a "bludge" subject, as you didn't have to do any work." (Entry C, 2021) "… students were not feeling rewarded for the hard work they were doing. The students in the class knew it was not a bludge" (Entry C, 2021) **"**The next problem we faced was how to come up with the A-E grade. We toyed with a few different [ideas]… [however] we settled on creating a rubric associated with the 21st century skills (QCAA, 2019)." (Entry C, 2021). **STEM Conference:** "The concept was that it was going to be like a professional development conference - students would be delegates who attended, learned, were served professional food, and given opportunities to network with speakers and other students." (Entry E, 2021) **Evolution of pedagogical strategies:** - **Years 1 – 2 (focus of teamwork and fluid groupwork, which can be seen as working well in Year 4).** "A bunch of us still wanted to do the personality types. Student B and Student C came together because we knew we'd work together and from there we grow. We added Student D and Student E. Student F, and Student G were here too but they left. This

			semester, Student G left to another group and Student D and Student E came to our group." (Entry V, 2021) - **Year 3 (focus on cognitive dissonance experiences)** "One key process that we feel has provided some key learning experiences in the Year 10 program, is the concept of creating cognitive dissonances." (Entry L, 2021) "For example… we intentionally giving them the wrong resources to respond to the problem. The intention is that they learn very quickly, through the process of asking for / wishing for something else, that choosing the right tool / resource for the task is really important in moving a project ahead…. [Or] we give them a very limited amount of time to complete a project. We ask too much of them within a short time period. The idea being, that they learn the process of planning and time management through the experience of working under extreme time constraints." (Entry L, 2021) "…it is important to ensure the first instance of cognitive dissonance that we create for the students to experience has a short working time, and they find out the "secret" that we (e.g.) gave them the wrong resources to solve the problem quickly." (Entry N, 2021) "The feelings of frustration are an important part of the experience but finding the balance between learning through emotive experience and giving up due to frustration is really important. If it goes on too long, they will feel disheartened and even angry. The time that you allow the experience to happen can be extended as they learn that it is a teaching tool, but the first one must be short and sharp." (Entry N, 2021) - **Year 4 (focus on evolving Year 9)** "…the year 9 program… has become too segmented and doesn't flow nicely into the year 10 program. Need to infuse more explicit teaching of the thinking skills. maybe make smaller chunked projects interspaced with other activities" (Entry G, 2021) "…the 10 STEM students still seem very limited in their thinking - even though the majority of them have been through the 9 STEM program. The 9 STEM program seems to be a bit too disjointed, without a resolution or flow to the discrete projects they have been completing" (Entry K, 2021)

			"We decided to move the 'Turtlegate intro to STEM', traditionally done at the beginning of Year 10, to Term 4 of Year 9. Not sure at this stage what we will move into Term of Year 10 - but perhaps some reflection with the current cohort as to what they think they are missing from the program" (Entry K, 2021) "Students need to be able to design their own learning from the viewpoint of organically seeking the skills, knowledge and expertise that is contextually needed at that point in time" (Entry T, 2021) "It's no wonder they [the students] find the STEM way of working hard to adjust to, when it's so different from their normal. I think that's why it's been really important to explicitly name Term 4 in Year 9 STEM "Unlearning how to learn". We have explicitly told the students that we don't want them to operate in the same way as their other classes. They need to unlearn their habits - particularly the habit of responding in ways that please the teacher. We are not looking for the answers in our heads - we want the answers from yours!" (Entry U, 2021)
	C - Purpose of curriculum		
	D - Purpose of education		
	E - Purpose of STEM education		
Constraints	A – Timetabling and resources	**The first enactment probably only actually happened because there was a gap the timetable and it filled a pragmatic need (A1). Now that Administration are faced with the 'harder challenge' – they seem to be backing off from their support.**	**Considering the future developments of STEM at PCC (keeping in mind Administration is suggesting moving it into lower years):** "There are significant timetabling and mindset in leadership issues that we will face to get this off the ground in primary school." (Entry H, 2021) A1 raised the thought, what if we started at the youngest end: Prep and Year 1. "Get them before we break them"." (Entry H, 2021) "Three times this year now, I have pitched the transdisciplinary STEM approach, with an expanded program that can even extend

		Two things needed to do this are room in the timetable and leadership / administration who are willing to take risks and do the hard work of making room.	to P-10, working within curriculum time. I feel like our Year 9-10 program provides a strong proof of concept, and that it's time for the next evolution / expansion. However yet again I am met with inaction. Their reasoning seems to be most strongly linked to making space in the timetable. There's no time/space to fit this in, therefore it won't happen" (Entry I, 2021) "…We were led to believe that STEM could be implemented with Year 7 and 8 next year, but now find out… that it won't be going ahead due to timetable issues" (Entry Q, 2021) **Things needed to get a STEM program like this off the ground:** "…two key things in getting a STEM program implemented in curriculum time would be timetabling, but also leadership who are willing to take risks and do the hard work of making room. (Entry Q, 2021) - **Link this to Admin/Constraints/B and Teaching Staff/Constraints/B** - **In this case study, timetable wasn't an issue to start with, and leadership were willing to take the risk due to a polished proposal. Now that timetable has become an issue, it's interesting that with a polished proposal, proof-of-concept AND admin who are feeling the guilt feelings that it's not being approved. There must be something else at play.**
	B – Curriculum and pedagogy	**I keep worry about how can we measure the growth in skills, but what I think I'm asking for is success criteria, because if a benefit can't be tangibly proven then the program may not continue. Admin are currently seeking that success criteria. Growth in skills is not**	**Links to Admin/Constraints/B and Teaching Staff/Constraints/B around only having anecdotal evidence of growth in skills:** **In reference to the captaincy interviews,** "…3 out of 4 candidates referenced their experiences in Year 10 STEM as to how they learned to work well with others. ADMINISTRATION STAFF described this as "proof of concept" that the STEM course is building soft skills in students, but also that they are reflective enough to be aware of it." (Entry S, 2021)

		typically measured in any other subject, so why should it be in STEM? Admin don't typically link (e.g.) success in Year 12 Biology to success in Year 10 Science – why should STEM be measured this way?	
	C - Purpose of curriculum		
	D - Purpose of education		
	E - Purpose of STEM education		
Ideologies	A – Timetabling and resources		
	B – Curriculum and pedagogy		**Ideologies sitting behind the structures of the curriculum and pedagogy in the PCC STEM enactment strategy:** - **Assessment ideologies:** "…we were… determined that students would be in charge of marking themselves / deciding what their work was worth - similar to a workplace self-appraisal and then meeting with a team leader." (Entry C, 2021) - **STEM Conference:** "The PCC STEM conference idea came from the need for students to widen their perspective of the types of problems they can solve" (Entry E, 2021) ***The purpose of the STEM conference was*** "…to find a way to get lots of different professionals from a wide range of industries to speak about their jobs and the types of problems they faced, to inspire students to think bigger. At its conceptualisation, STEM conference was meant to be an idea-generating or inspiration tool." (Entry E, 2021) - **Course structure ideologies**

			the point of the Year 9 program is to give many and varied opportunities for skill and knowledge development, as well as soft skill development (trial and error, reiterative process of design)"
	C - Purpose of curriculum		
	D - Purpose of education		
	E - Purpose of STEM education	**Seems that once I initially formed my view, it didn't change too much. Maybe that resolve / commitment to a visualization of STEM is helpful?**	**Pre-enactment phase:** "I didn't really understand what STEM was, except for Science Technology Engineering and Mathematics. I didn't understand how these things could be taught together at the same time, with students effectively learning the depth of knowledge that each of these things bring." (Entry A, 2021) **After ideating, I realized that** "I knew that I couldn't do it by myself, that I would need the Engineering and Technology knowledge bases to help. So, I reached out to T2, my counterpart LT of Design and Technology to see what he thought. I pitched the idea of the subject to him, including a few key thoughts around team teaching, facilitating expert knowledge into the classroom instead of teaching, the key focus on problem-solving and the next step of enacting solutions - not just writing an assignment about what they would do... they actually had to do it" (Entry B, 2021) **Recent enactment phase:** "An alternate view of the current landscape of STEM education in Australia Lack of refinement in Australian publications is often suggestive of inclusiveness – allowing teachers and schools to take whatever approach they want and still be able to categorise it as STEM education. However, in [recent] curriculum specific events, there seems to be a focus increasing clarity and decreasing confusion. This seems to lead towards more prescriptive boundaries in educational contexts… So, with that in mind – for all my discomfort or frustration with the lack of clarity – I probably wouldn't have been able to implement our particular STEM program if I was working with a prescriptive definition." (Entry R, 2021)
Character types	A - Teacher/s		**Teacher mindset:**

			"The role of the teacher and the mindset of the teacher is so important" (Entry E, 2021) **Teacher identity:** "…T2 integrated into the team perfectly. T2 was open to try new things, had a growth mindset and acknowledged that T2 wanted to learn how we do it. The observation period was so important - allowing T2 time to observe the ways we talk to students, how we interact with the class, how we question ideas and provide feedback." (Entry J, 2021) "I believe within our transdisciplinary approach to STEM, all teachers could provide unique knowledge, skills and perspectives that would be valuable resources to students in the class." (Entry T, 2021) "Who a person is, their socialisation into the teaching profession, their educational philosophy and their futurist mindset all play integral roles in making someone a STEM teacher." (Entry T, 2021) "The natural style and flair of a teacher has to show through in the classroom. Teachers who are strict rule enforcers need to be accompanied by another teacher who can balance their approach. Key to their education philosophy needs to be an openness to take pedagogical risks, strong reflective practice, willingness to open their classroom to others (other teachers, professionals, etc), and a growth mindset in their approach to their own practice." (Entry T, 2021) **Character types that would not work in a transdisciplinary pedagogical environment:** Some qualities or practices that would be harmful to the transdisciplinary approach would be a [unwavering] traditionalist view of education, where the teacher is the expert and the students are sponges, absorbing knowledge in a one-way transaction; a silent classroom; worksheet approaches; textbook teaching; pure chalk and talk all the time teaching" (Entry T, 2021)

	B - Curriculum leader/s		
	C - Senior teacher/s		
	D - Administration		
	E - Student/s		
Roles	A - Teacher/s		**Team-teaching** “The team-teaching aspect of our enactment strategy is crucial to the success of the whole operation” (Entry O, 2021) **Facilitators** “it's a whole different mindset from my other classes. I often use the walk between classes to reset my mind - to change from the structured minute-by-minute plan I have in my Maths or Science classes, to the problem-based questioning style of facilitative teaching that I use in the STEM classroom.” (Entry U, 2021)
	B - Curriculum leader/s		
	C - Senior teacher/s		
	D - Administration		
	E - Student/s		
Assumed character types	A - Teacher/s		
	B - Curriculum leader/s		
	C - Senior teacher/s		
	D - Administration		
	E - Student/s		
Assumed roles	A - Teacher/s		
	B - Curriculum leader/s		
	C - Senior teacher/s		
	D - Administration		A1 acting as a mediator for the teaching staff within the program when conflicts arose: “… For months, we found it difficult to speak to each other and communicate at all. We basically communicated through a mediator / third party” (Entry F, 2021)
	E - Student/s		**[TEACHER] interviewed a group of students who were working particularly well together, to gain their perspective of how students can successfully engage in STEM.** - “Communication, definitely” (Entry V, 2021)

			- “the variety of skills that we brought to the group, and the fact that we used the MBTI personality types. We chose this group based on the range of personality types.” (Entry V, 2021) - “…we all come together for a common goal, we all want to pull our own weight, we all have the motivation to do this.” (Entry V, 2021) - “It has grown while working together because I can see how well we are working together and that inspires me to do more. The motivation and teamwork snowballed - we all started with a common goal, but it grew as we moved along” (Entry V, 2021) - There are friends within the group. So, taking a friend with you makes you feel more comfortable” (Entry V, 2021) - “Put a lot of effort into deciding who your group is, it's worth it in the end. Being able to get over the obstacle of leaving people that you're comfortable with.” (Entry V, 2021)

Appendix 3 – Analytic Memos: Semi-structured interview data (Administration staff)

Secondary code	Tertiary codes	Source & Memos	Direct quote and Memos
Goal oriented behaviours, acts or activities	A - Negotiating	A1, p. 5, 6 **Negotiating around what types of problems students would engage with occurred during the early implementation phase**	"Initially the types of problems we thought students would engage with was quite different to what they were engaging with… we realized students needed help identifying actual wicked problems and then framing those problems before solving them" (A1, p. 5) **During early implementation, problems students wanted to solve were described by A1 as** "very here-focussed rather than those bigger picture, real-world, meaningful problems" (A1, p. 5) **In reference to having to assist students in framing up problems, a critical element of STEM enactment at PCC, A1 describes it as** "something that we maybe didn't - I certainly didn't anticipate" (A1, p. 6)
	B - Blaming		
	C - Leading	A1, p. 4 **PCC could be seen as leading the way in policy enactment, within curriculum time.**	"It's a priority" (A1, p. 4) – **in reference to why it was approved to run as a subject within curriculum time. Administration saw the proposal for the activity as something important that was missing from the students' current experience of school.**
Emotion oriented behaviours, acts or activities	A - Complaining		
	B - Compensating		
	C - Watchful	A2, p. 7 A1, p. 6 **Administration seem to be aware of policy imperatives such as workforces of the future, yet don't specifically refer to the policy documentation.**	"If we're not training up students to actually deal with [complex problems] and walk in that space, then we've actually done the next generation a disservice" (A2, p. 7) **As the PCC enactment strategy looks to the future, Administration seem to be in a watchful phase. They seem to be looking to curriculum leaders for guidance around what it will look like into the future, knowing they want it to be future-proofed and sustainable.**

			"…for the current team, I think what's been really important has been the unity of purpose and staying pure to what it is, or evolving together in our thinking as we keep learning and growing in our understanding" (A1, p. 6) "… the future of our work is looking like it's going to be more around those [problem framing and solving] skills rather than being an expert in a particular area, though of course both are needed" (A1, p. 9)
Rules	A – Timetabling and resources		
	B – Curriculum and pedagogy	A1 p. 2, 3 **Current enactments of STEM across Queensland seem to focus on the discrete subjects, <u>as opposed to the policy imperatives</u>**	**These three quotes demonstrate current enactments of STEM in other places, as viewed by Administration staff at PCC. They recognize that this is different to the PCC enactment strategy.** "It seems to be quite varied across Queensland when I look at what we're doing to other schools" (A1, p.2) "… broadly across Queensland, STEM would be focused on the discrete subjects, the science the maths and the technologies particularly" (A1, p. 2) "It's often with a technology component, the drones and robots… seem to have the focus" (A1, p. 3)
	C - Purpose of curriculum		
	D - Purpose of education		
	E - Purpose of STEM education		
Structures	A – Timetabling and resources	A2 (p. 5, 6) A1 (p. 4) **Within the case study, timetabling wasn't an issue due to there being space in the subject lines for Year 10. However, PCC**	**At PCC, STEM was approved to be enacted in curriculum time because** "We were in a good place to take a risk on a room". (A2, p. 5) "… at a very pragmatic level, it fills a gap" (A2, p. 6) "… resourcing hasn't been an issue for us… [it's] been really helpful, not having to create a whole STEM lab before we could even start… we've been able to work with what we have" (A1, p. 11)

		(A2, A1, T1) recognizes that this can be a significant hindering issue. – See Constraints (A)	**At PCC, STEM is set up as a part of the curriculum, for the purpose of moving beyond superficial enactment of policy directives.** "By having it as a part of our curriculum, [students have] a whole year of focus time" (A1, p. 4). "… they can really take on that transdisciplinary approach and go beyond… an add-on" (A1, p. 4)
	B – Curriculum and pedagogy	A2 (p. 4) A1 (p. 5) **Lists of curriculum structures that administration think will make STEM work.**	**Both A2 and A1 describe a student-centered pedagogical framework that has elements of problem-solving and inquiry. A1 acknowledges the lack of curriculum content.** "collaboration, the problem-solving approach, good questions of inquiry… and practical… [and] student agency… which goes hand in hand with that inquiry" (A2, p. 4) "the design process has been used a lot… it's very much problem-based… and elements of inquiry… the students having freedom to guide where they go instead of having a set of curriculum content" (A1, p. 5) A1 describes the program as "student-centered", "meeting the students where they're at, and allowing them to direct their learning" and "collaborative" (A1, p. 5) **Other things that have been key structures in the curriculum setup:** "STEM conference was awesome" (A1, p. 12)
	C - Purpose of curriculum		
	D - Purpose of education		
	E - Purpose of STEM education	A2, p 2 A1, p. 6 **Problem-framing as an important structure in the PCC**	"We went on our own journey of understanding… about what STEM is, and what it might look like at Parklands" (A2, p.2) "If it's just about problem-solving, then in a sense you kind of have to give them the problem…. For them to just focus on the solution part of it. Whereas, if we actually want the students to choose

		STEM enactment strategy	something that's meaningful to them that they're passionate about, then they need those skills to be able to… frame it so that they can move onto the solution" (A1, p. 6)
Constraints	A – Timetabling and resources	**Repeated use of the word challenge suggests admin are willing to try this – they didn't say impossibility**	"a… logistical challenge" (A1, p. 9) "… it's created a lot of good challenge for the executive team as well as the education team" (A1, p. 11)
	B – Curriculum and pedagogy	(A2, p.2;3;4) **Moving from thinking something is exciting to actual enactment is difficult. What happens between thinking something is worthwhile and overcoming the obstacles to actually enact it?** **As seen in the Ideologies (E) – ideologically, the skills required are different to how teachers naturally operate. Therefore to expand or even transfer the program there are current constraints around teacher training.** **Transdisciplinary enactment in curriculum time**	**What is STEM in other places?** "STEM has been around as a concept for quite some time, but it depended on who you asked, it would give you very different answers [and] feedback about what STEM was" (A2, p.2) "It's like, what does STEM mean to you?" (A2, p.2) "…typically, you go and see a facility at a school, and they say they've got STEM, there's robots and engineering type stuff. That's about it" (A2, p.3) **It's a risk, for both teachers and administration:** "a teacher needs to see the opportunity for innovation and collaboration... taking the risk of student agency, because that in itself is risky for a staff member" (A2, p. 4) "… it's a big risk. And if this goes badly, it's going to be on me" (A1, p. 9) **Constraints to actually getting something off the ground:** - **Having action-oriented people** "I'm the kind of person that goes, "ooh, that sounds new and creative. Let's pursue that… but if I actually had to do something, that would not excite me" (A2, p. 5) - **Financial concerns** "… budget is a serious consideration. How do we actually pull this off without spending any extra money?" (A2, p. 6) - **Sustainability of staffing** "… projects like these are as good as the staff that you have at the time. Longevity for me is a concern." (A2, p. 6)

		presents a significant challenge, and it's easier to stay in the coding club realm. But what actually is the challenge? Admin perspective suggests timetable, risk management, teacher mindset and teacher training.	When discussing how to expand/evolve the PCC enactment strategy, A1 suggests that "I'm not exactly sure yet what we do with that, but I think it's something we're going to have to keep working through if we're going to bring others into the program" (A1, p. 7) **Enactment during curriculum time is a challenge, and there are easier ways to do it:** "It would be much easier for schools to stay in the coding club or the cross-disciplinary moments rather than going to the transdisciplinary. It's a harder challenge" (A1, p. 8) "… if we were trying a club and it didn't work, you go 'okay cool, that's fine.' We can take those sorts of risks. But a whole year's worth of education, if it hadn't gone well, that was a significant risk to take" (A1, p. 10) **Constraints of the current implementation strategy / areas that need further research:** - **How can we tangibly assess the growth in soft skills?** "I don't have the specific data… but I would think that from what I'm hearing, they are growing in those areas" (A1, p. 10) **Anecdotal evidence from an administration perspective arose during captaincy interviews, where** "a few of [the candidates] referred to STEM as an example of where they'd learnt those skills really well" (A1, p. 10) - **How to expand the program** "…[teachers] are aware they should be incorporating STEM into their classrooms, but they don't know how, they're too busy" (A1, p. 12) "…if we can get in with those littler ones and get them developing the skills earlier on, I think the whole school will benefit from that as well as the students themselves" (A1, p. 12). **Interesting note the "whole school will benefit" – should have asked benefit in what way?**
	C - Purpose of curriculum		
	D - Purpose of education		

	E - Purpose of STEM education	(A2 p. 3) **Administration suggest that STEM and its purpose needs to be clarified. The overarching policy does seem to have a consistent, agreed upon 'purpose', but current enactment across Queensland is so varied that the purpose is blurred.**	"Unfortunately I think most…schools, when they think of STEM… it's this engineering concept. It's not untrue, but it's not the full picture of STEM" (A2, p. 3) "STEM needs more clarity… and purpose in our schools. It makes sense to me, and I want to pursue it, but a necessary part of that journey is clarifying that purpose and its place in a school. It's giving it legitimacy along that journey" (A2, p. 5)
Ideologies	A – Timetabling and resources		
	B – Curriculum and pedagogy	(A2 p.4) A1, p. 7 **Ideologically, the skills and pedagogies required seem to be in contrast with the way teachers are currently trained and operating in discrete classrooms**	"to approach anything in a school from a transdisciplinary approach it not only goes against our training, but the way we form our institutions" (A2, p. 4) "In terms of the skills they need… it's not what comes naturally to teachers… it's actually quite challenging to switch to a different way of thinking" (A1, p. 7) "… it's not necessarily natural to the way teachers work. [Teachers have been] trained to work in ways that are kind of linear in many respects, whereas…. To facilitate this approach, with its intended purpose, it actually requires a teacher to be a much more lateral thinker" (A1, p. 7 but said by TD).
	C - Purpose of curriculum		
	D - Purpose of education		
	E - Purpose of STEM education	(A2 p. 2; 3; 6) **Benefits and advantages are not**	"it's a transdisciplinary approach to a few subjects", "[it] answers a gap in our society in the journey from students to grade 12 and to university as well" (A2, p.2)

		clear in the program yet. Administration still speak about what they "hope" the program will achieve.	"It's a promotion of a group of subjects but… it produces something that's truly pragmatic. Something that is tangible and that we can link to beyond school" (A2 p. 3) "I was inspired to think that our students could have a richer learning experience with the presence of a STEM program" (A2, p. 6) "It sounded reasonable enough… but it also sounded inspiring that this could be something that not only changes our school, but possibly could invest in the future of STEM in Queensland and our national curriculum" (A2, p. 6) "I hope that it will give tangible outcomes in terms of helping our kids lead their own learning journey, take risk, value agency and become good critical thinkers outside the creative subjects" (A2, p. 6) "… our world needs creative people… and… that is going to be increasingly so in our future. That we're going to need creative solution to complex problems" (A2, p. 7)
Character types	A - Teacher/s	A2, p. 5 **This could speak to how administration see STEM teachers, which may contrast to / agree with how STEM teachers see themselves.**	"the teachers themselves need to be inquisitive. They need to actually see themselves as learners as well" (A2, p. 5) "… the teachers have to have those same thinking skills themselves" (A1, p. 7) Teachers need to be "comfortable with being responsive… In the moment they've got to be able to draw on what they know and decide on what's the best approach here for this student with this problem" (A1, p. 7 – but actually said by TD. A1 response is "Yeah absolutely") The teachers must "know where they want to go… but be able to roll with what the student's talking about, or be able to facilitate the students working together. The staff need to have those skills,

			rather than just some knowledge" (A1, p. 7) **"JUST some knowledge" suggests that knowledge is important but is only the beginning of what a teacher needs to function in a transdisciplinary pedagogical framework.**
	B - Curriculum leader/s		
	C - Senior teacher/s		
	D - Administration		
	E - Student/s		
Roles	A - Teacher/s	A1 (p. 5, 7) **The admin perspective of the teacher's role is to model current and future workplace structures and functions.**	**Admin describe the roles of STEM teachers:** "the staff work in teams" (A1, p. 5) "collaborative teams" (A1, p. 7) Teachers will have "…training on… a whole range of different types of pedagogies to be able to pick and choose from them for what's needed in the moment" (A1, p. 7) "…instead of seeing that* as incompetence, it's actually realizing that that is modelling how these students are probably going to be working in their workplaces" (A1, p. 9) ***" that" being a pedagogical shift of flexibly responding to students' needs, rather than functioning as a content expert.** "…teachers have a really important part to play in modelling… collaboration between teachers and… drawing on each other's strengths" (A1, p. 9).
	B - Curriculum leader/s		
	C - Senior teacher/s		
	D - Administration		**Administration engage with the STEM class by listening to student pitches if they involve actions on school site. They give approval or non-approval to implement projects.** "Students were coming to me pitching what they wanted to solve" (A1, p. 5)
	E - Student/s		
Assumed character types	A - Teacher/s	(A2, p.4) **The first people on the project need to be passionate. Their passion then needs inspire a small**	"[staff members] need to be collaborative [and]… because of the newness of it, [have] a fair bit of innovation and creativity" (A2, p. 4) **Staff need to be passionate about doing this:** "if you've got somebody passionate to pursue a project, then that's half the battle won" (A2, p. 5) "… staff who are passionate and well informed" (A1, p. 10)

		number of others before more the program can grow. **Administration describes the character types they would like to see assumed within the subject. Don't specify teacher or student but say "people".**	"I'm inspired to think we can have me really great critical and creative and innovative people subjects that are not stereotypically creative" (A2, p. 6). **Interesting use of "people" in this quote – he doesn't specify student or teacher. Also reinforces the position in the next quote:** "I'd love to see some creativity in our school that doesn't revolve around the humanities and the arts" (A2, p. 7) **A1 expressed a desire to enter the classroom in a teaching capacity, but articulated that it would be challenging, in terms of mindset and skill set. This may be representative of how teachers may feel before embarking on a transdisciplinary pedagogical journey.** "I would love to get into the classroom and be involved in that. But I think it's a challenge for me, because my thinking has been a certain way for so long, how well would I do in that?" (A1, p. 8)
	B - Curriculum leader/s		
	C - Senior teacher/s		
	D - Administration		
	E - Student/s		
Assumed roles	A - Teacher/s	(A2, p. 7) **Administration describing the roles that they hope the teachers can play in creating a STEM program.**	"I'm excited to think we could have a faculty that is dedicated to inspiring students to be critical thinkers. To be problem solvers. To be engaged in solving real world problems. And using their Maths and Science, all of those things" (A2, p. 7)
	B - Curriculum leader/s	A1 (p. 4) **To enact a project like this, there needed to be research focused curriculum leader to speak to manage the risk.**	**[TEACHER] assumed the curriculum leader role throughout the research journey that led to enactment. Administration had trust in the project because of the research and proposal that was brought forward.** "Early on, when we were discussing this [teacher] brought research forward, and put forward the proposal… that the thinking skills [students would develop] would help any subject" (A1, p. 4)

		The "success" (A1, p. 11) of the STEM program has allowed curriculum leaders to assume the role of change agents within the PCC educational philosophy	"[Teacher] had done so much research beforehand – [they]'d gone to schools, [they]'d gone to professional development, [they] had done the readings – that gave me that sense of security in that okay, this is worth the risk" (A1, p. 9) **Curriculum leaders on this project may assumed the role of change agents in the PCC environment:** "… it's been good in modelling to the rest of the school, trying something new, doing some research, getting outside of… do[ing] what we always do" (A1, p. 11) "… it's constantly… there as that little bit of challenge to our thinking." (A1, p. 11) "… we've started some broader discussions as… we've got his case study sitting there as a success". (A1, p. 11)
	C - Senior teacher/s		
	D - Administration		
	E - Student/s		

Appendix 4 – Analytic Memos: Semi-structured interview data (Teaching staff)

Secondary code	Tertiary codes	Reference	Direct quote
Goal oriented behaviours, acts or activities	A - Negotiating		
	B - Blaming		
	C – Leading As in, "leading change"	**Compare these behaviours to the assumed character types of teachers from the admin perspective. Are teachers functioning in the way that admin assume they are?**	**Teaching reflexively and responsively to the students:** "… it's very much about getting a feeling for where those students are at and adjusting it [the teaching and learning approach]… some of them may need a bit more of something" (T1, p. 5). ***T1 agrees with A1s expectations of teaching from a pedagogical bank and flexibly responding to the students' needs.*** "… very much back and forth between us and the students. Lots of communication… Lots of feedback… [and] short intervals, just to keep the temperature of the room". (T1, p. 6) "let them get off track sometimes as well, because that's a good thing to learn. There is an experience in there as well" (T1, p. 6). "I like to think, what are the steps I would go through there, and then try to get them to think about those same sorts of things" (T1, p. 7). **Using questioning techniques:** "What's it like? Where's everyone at? Are you understanding? Are you on track? Have you deviated by far? Do I need to intervene a bit more, or do I need to give you a little bit more freedom?" (T1, p. 6) **Strategies used when working with students who aren't comfortable in the open-ended environment:** "I feel that those students, they like structure… we have to change our approach a little bit and just work a lot closer with them. Maybe giving them a little bit more guidance, a little bit more scaffolding, and slowly ease them towards the… open-endedness" (T1, p. 7). "… give them a bit of scaffolding around feeling secure so that they think, "Oh, actually I have got a bit of structure, it's not as bad as I thought." As they get more and more comfortable, we can take away [the scaffolding]." (T1, p. 8)

			Exposure to open-ended problem solving: "By exposing them to these problems and allowing them to come up with their own solutions and… their own problems, we're changing the way that they think, and then they can apply that across all spectrums. Whether it's another subject, whether it's when they go home, out into the community. As you're changing their brain, they take their brain with them everywhere" (T1, p. 9) **Activities that increase awareness and understandings of self, teams and society:** "…one of the things we did… was expose them to… MBTI. And we talked about working in groups and solving problems in teams. And having those different skills of people that you need to solve problems. That you might need to engage with different people sometimes. We…try and get them to think about… maybe don't always go with your friends." (T1, p. 10).
Emotion oriented behaviours, acts or activities	A - Complaining		**Students can feel frustrated at the process:** "…they can get quite frustrated as well, and some of them have expressed that, that they're not happy" (T1, p. 8)
	B - Compensating		
	C - Watchful	**Students can easily feel frustrated by the cognitive dissonance and pain of learning. Empathy and understanding of the process will be important parts of a teacher's character. Are these present in the "character roles"?** **Administration and teaching staff agree that future visions of STEM have it expanded to include**	**Descriptions of student behaviour:** "Some of them really embrace it and they do really well. Whereas others, it's not as much their cup of tea, so they won't engage to the same extent" (T1, p. 5) There has been "… change towards self-improvement… and becoming more proactive, …asking for feedback, …[and] taking on advice as well" (T1, p. 10) and students are "less afraid to not always have it right… [they're] happy to be able to accept that this is good enough for now… to keep moving forward and improving" (T1, p. 10 but said by TD, to which T1 responded "Yeah."). "… it's a little bit hard for students to sometimes break their habits of, "I'm at school, I'm in a class, so I don't do anything" … it's nice to have a little subject [where] they're allowed… to do something different, …have a little bit of fun and then talk about what they did." (T2, p. 10) **Future visions of STEM, from a teaching staff perspective:**

		more students. Admin are more visionary in terms of which students, teaching staff are more pragmatic in terms of how to do it.	"it's always about continuous improvement… eventually seeing it… spreading more throughout the school." (T1, p. 11) "I think what's more important, especially [in] this pandemic era that we've been living through, is the ability to plan and adapt... It's far more serious to teach our students those skills, to plan and adapt, change, innovate and keep on going forward to reach a goal" (T2, p. 11)
Rules	A – Timetabling and resources		
	B – Curriculum and pedagogy		
	C - Purpose of curriculum		
	D - Purpose of education		
	E - Purpose of STEM education		
Structures	A – Timetabling and resources		
	B – Curriculum and pedagogy	T1, p. 3 **Curriculum structures that teaching staff have been utilizing within the STEM classroom. How does this compare to the Admin perspective of what they think the course needs?**	**Course structure of PCC enactment strategy:** - **Skills and problem focussed** In Year 9, the course is about "exposing them to STEM… and getting them building some skills that they can use. By doing lots of smaller projects, building up skills… we can [then, in Year 10] expand that out and do some bigger projects and come up with their own problems" (T1, p. 3) - **Open-ended** T1 describes the approach to teaching and learning as "very open-ended and multiple entry and exit points… because different kids and different" (T1, p. 5) - **Cognitive dissonance opportunities** "… set a task that is very difficult for the student and they're meant to struggle with it… in order to learn along the way. It's very collaboratively and… we encourage self-efficacy… in order for the students to reflect on how they're going and reflect on their own work and if they're reaching their goals. (T2, p. 5) **Describing the program as "student centred":**

			"… student-focused… or student-centred is probably a better word. Or student-driven maybe" (T1, p. 4) "…student-centred, project-based learning" (T2, p. 5)
	C - Purpose of curriculum		
	D - Purpose of education		
	E - Purpose of STEM education	**Admin and teaching staff in agreement that problem solving, and problem framing are important aspects of the STEM course.**	**Outcomes PCC enactment strategy is trying to achieve:** "Problem solving is one of the main ones… [and] understanding a problem or a situation. Being able to interpret it, break it apart, and see what are the various… aspects that are involved with this problem? And then what do they actually need, or how do they address it? Once they've done that they can then start to tackle, okay, how do we address this problem? So, what resources do I need? What knowledge do I need? What sort of people would I need?... How do I engage those people? How do I communicate? And… then present their solution" (T1, p. 3) "… allowing students to learn how to problem solve, which is something that then they can take to other subjects further down the track into life and so on, like these skills that overlap all these different industries that allow them to be exposed to a range of problems in order for them to adapt to the future and adapt to changes." (T2, p. 8).
Constraints	A – Timetabling and resources		
	B – Curriculum and pedagogy		**Constraints of current implementation strategy / areas that need further research:** **Assessment strategies to show growth in skills and intended outcomes. At the moment, it's really only anecdotal evidence (seen in A1, p. 10, and T1, p. 10) –** "I have seen a change with one particular group this year that's really embraced it… they're working a lot better together" (T1, p. 10).

			Link to A2 comment around if he actually had to do something it would not excite me / constraints of actually getting a program off the ground: "…you come across something that's like, "This is different. Yeah, I'll give that a go." Then six years later you're sitting here going, "Yeah, that was a lot of work."" (T2, p. 7) **Reservations in the development phase:** "How do we make this not just science?... how do we actually make this something different that is its own thing" (T2, p. 8)
	C - Purpose of curriculum		
	D - Purpose of education		
	E - Purpose of STEM education		
Ideologies	A – Timetabling and resources		
	B – Curriculum and pedagogy		
	C - Purpose of curriculum		
	D - Purpose of education		
	E - Purpose of STEM education	T1, p. 2 **Admin definitions of STEM generally include the stereotypical/common enactment strategies. Whereas teaching staff subscribe to the**	**Definition of STEM education:** "… a combination of the various topics that make up the letters… [and]… exploring the application of those subjects." (T1, p. 2) "… it's more around the how do we bring those subjects together to solve problems? And how do we actually use them in real life?" (T1, p. 2) "…trying to address the 21st century thinking skills through engaging tasks that are generally centred around a project or a central problem or like a wicked problem. But they are generally trying to address… future needs, while teaching the students about how to innovate or think creatively." (T2, p. 2) "… the interconnective nature that you're trying to get in the course is not a namesake, is not just science, technology, engineering, maths." (T2, p. 5)

		contemporary, PCC version of STEM when providing a definition. Teaching staff seem to have each personally adopted the policy defined broad scope, whereas Admin seem to define STEM according to cross-discipline subject teaching + technology focus. **T1 confirms that the program is providing a richer experience (p.9), which A2 expressed as a desire for the program (p. 6).** **PCC could be characterizing a "rich learning experience"**	"… it's the thinking skills that we're trying to teach across it. We're not intentionally trying to teach Science, yes we will; we're not intentionally trying to teach Maths, yes we will though, but we're trying to teach… the skills that bend across those things" (T2, p. 6). ***When describing STEM programs witnessed in other places, T2 suggests that*** "it may be based more off art and design curriculum more than it should be and would be less curriculum-focused" (T2, p. 4) ***Describing the STEM program at PCC:*** "for the students to learn in a rich way what the 21st century thinking skills are, in order for them to be innovative and adapt to a range of curriculum problems or life problems, to allow them to think collaboratively, think of other people's needs, to change their plan along the way, while critically thinking and creatively thinking." **At PCC, the purpose of the STEM program is:** - **Providing a rich experience:** "…[we're] providing different experiences, richer experiences" (T1, p. 9) "… we're preparing the kids to think… what type of person are they going to be when they leave school and go into the workforce?" ***Interesting that T1 used the phrase "what type of person" they are going to be, as opposed to "what skills they will have". Are we are preparing people, not workers?*** - **Preparing students for the future:** "… the world is changing… I don't know what it's going to look like, but we're going to need people to solve problems." (T1, p. 9) ***T1 uses the phrasing "we're going to need people to solve problems" as opposed to "we're going to need people who can solve problems". Are we preparing the person, not the skills?***

		as one that develops the PERSON, not their knowledge and/or skills.	
Character types	A - Teacher/s	T1, p. 6 The idea that teachers need to be the type of learner they are trying to mould agrees with the Admin perspective of how they view a STEM teacher (A2, p. 5; A1, p. 7)	**A teacher's perspective of the character types needed to be a STEM teacher:** **The skills:** "We have to have that mindset as well ourselves… those problem-solving skills. All the skills we want to teach them I guess we need to have ourselves too" (T1, p. 6) **Patience:** "You need to be patient and have a bit of empathy as well. And just get alongside them and support them" (T1, p. 8) **Interest:** "Already being in that sort of field… and coming from an engineering field, I was quite interested in getting involved" (T1, p. 8). "I just love anything that's a new challenge… [and] teach[ing] innovative skills to students is something that really appeals to me." (T2, p. 7) **A learner's mindset:** "… teaching is a career [of] lifelong learning. A teacher never gets to a point and says, "I know everything." So, of course, you're always looking for further development" (T2, p. 6) **Collaboration:** "… I couldn't point to [things] in our course and say, "That's mine" or anything like that, because it's so entwined, because it was a team effort." (T2, p. 6) "… to collaborate with staff from other silos and different subjects, forces a different way of talking" (T2, p. 8) **Give it a go attitude:** "…you come across something that's like, "This is different. Yeah, I'll give that a go." Then six years later you're sitting here going, "Yeah, that was a lot of work."" (T2, p. 7) "… you need staff who aren't afraid of innovating and having that fun, because I think some staff would be very scared if they – like just, "Hey, you're going to be collaborative teaching with someone from a different subject area to teach kids problem-based learning" and I can imagine that scaring some people" (T2, p. 8)
	B - Curriculum leader/s		

	C - Senior teacher/s		
	D - Administration		
	E - Student/s		
Roles	A - Teacher/s	T1 p. 4	**How teaching staff see their role:** "… I see my role more… as a facilitator and… a prompter. [However]… there are certain skills that they do need to be taught. There is an element of direct instruction for certain things." (T1, p. 4) ***An example of direct instruction as described by T1 is data interpretation.*** "… if they haven't come across those topics in Maths, for example… there might be a situation where we have to teach that directly.". (T1, p. 4) "what's really important… is having a teacher who can recognize when they need to work responsively… [and] that it's an approach that requires you to look at who's in the room, look at the problem that's been framed up, and then to be able to reach out to whatever approach you need to help facilitate a resolution" (T1, p. 5 – but said by interviewer. T1 responded with "Yeah, that sounds about right").
	B - Curriculum leader/s		
	C - Senior teacher/s		
	D - Administration		
	E - Student/s		
Assumed character types	A - Teacher/s		
	B - Curriculum leader/s		
	C - Senior teacher/s		
	D - Administration		
	E - Student/s		
Assumed roles	A - Teacher/s		
	B - Curriculum leader/s		
	C - Senior teacher/s		
	D - Administration		
	E - Student/s		

Appendix 5 – JCU Ethics Approval

This administrative form
has been removed

Appendix 6: Principal approval to name Parklands Christian College

This administrative form
has been removed

Appendix 7 – Standardised set of interview questions

Research Question One: Defining STEM

- How would you define STEM education in Queensland?
- How did you form this definition of STEM Education in Queensland?

Research Question Two - Conceptualising current STEM initiatives

- Have you witnessed STEM education in other school contexts that you can describe?

Research Question Three - STEM at Parklands Christian College

- What do you think is the purpose of STEM Studies at Parklands Christian College?
- How would you describe the approach to teaching and learning in STEM Studies at Parklands Christian College?
- Do you think the approach to teaching and learning in STEM Studies class meets the overall purpose of the subject?
- Do you think PCC team have the skills and knowledge necessary to implement STEM curriculum?

Research Question 4 - Principles of enactment from PCC case study

- Administration: What was your initial reaction to the proposal of STEM Studies at Parklands Christian College?
- Teaching staff: What was your initial reaction to the idea of having to teach STEM Studies at PCC?
- What motivated you to participate in the STEM Studies program at PCC?
    - *How does the role of each person affect what they see the benefits of STEM Studies at PCC to be?*
- Administration: What reservations did you have about implementing STEM Studies at Parklands Christian College?
- Teaching staff: What reservations did you have about teaching STEM Studies at Parklands Christian College?

- Administration: What led you to approving the implementation of STEM Studies at Parklands Christian College?
- Overall, do you feel that STEM Studies at Parklands Christian College provides any benefits or disadvantages the school community? In what way?
- Administration: Do you support the continuation of STEM Studies at Parklands Christian College? What is your vision for the future of STEM Studies at PCC?
    - What changes would you like to see? Why?

Appendix 8 – An excerpt of the Parklands Christian College STEM Studies work program

YEAR 9-10 STEM

Parklands Christian College 2022

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Figure 2. QCAA defined 21st century skills

1.0 STEM at Parklands

STEM Studies at Parklands Christian College is an elective subject that can be chosen in Year 9 and Year 10. This school-based subject was developed as a research-based enactment of national STEM policy agendas. It utilises a transdisciplinary, applied pedagogy that privileges student agency and the development of the 21st Century Thinking Skills (QCAA, 2019a). Within the course, students are exposed to authentic, real-world issues, and guided to produce tangible solutions within niches of tightly framed problems.

2.0 How is STEM education defined in policy?

Defining STEM education in current policy documents is a complex notion, and in the current landscape of publications, near impossible. Seminal publications from a range of authoritative voices do not present a clear, unified picture. Some policy documents refer to a segregated definition of S.T.E.M., where the acronym is referring to a suite of discipline-based subjects. “Science, Technologies, Engineering and Mathematics make up the STEM learning areas. The STEM learning areas are a key national focus for school education in Australia and are critical to equip students to engage productively in a world of rapidly changing technology” (Education Council, 2019a, p. 15). Other documents refer to an integrated definition of STEM, where the four areas are taught together, usually through a problem-solving pedagogy. “STEM education is a term used to refer collectively to the teaching of the disciplines within its umbrella – science, technology, engineering and mathematics – and also to a cross-disciplinary approach to teaching that increases student interest in STEM related fields and improves students’ problem solving and critical analysis skills” (Education Council, 2015, p. 5). Outside of national interests, prominent research suggests an integrated approach to STEM, involving teaching knowledge and skills from each of the disciplines together, or at least linking two or more learning areas to each other. In this view, one of the key aims of integrated STEM is to demonstrate how

STEM skills can be applied to authentic problem solving (English, 2016; Honey et al., 2014; Lowrie et al., 2017). At the end of the spectrum of integration lies the concept of 'transdisciplinary STEM'. English (2016) defines a transdisciplinary approach to STEM implementation as one "where knowledge and skills from two or more disciplines are applied to real-world problems and projects with the aim of shaping the total learning experience" (p.1).

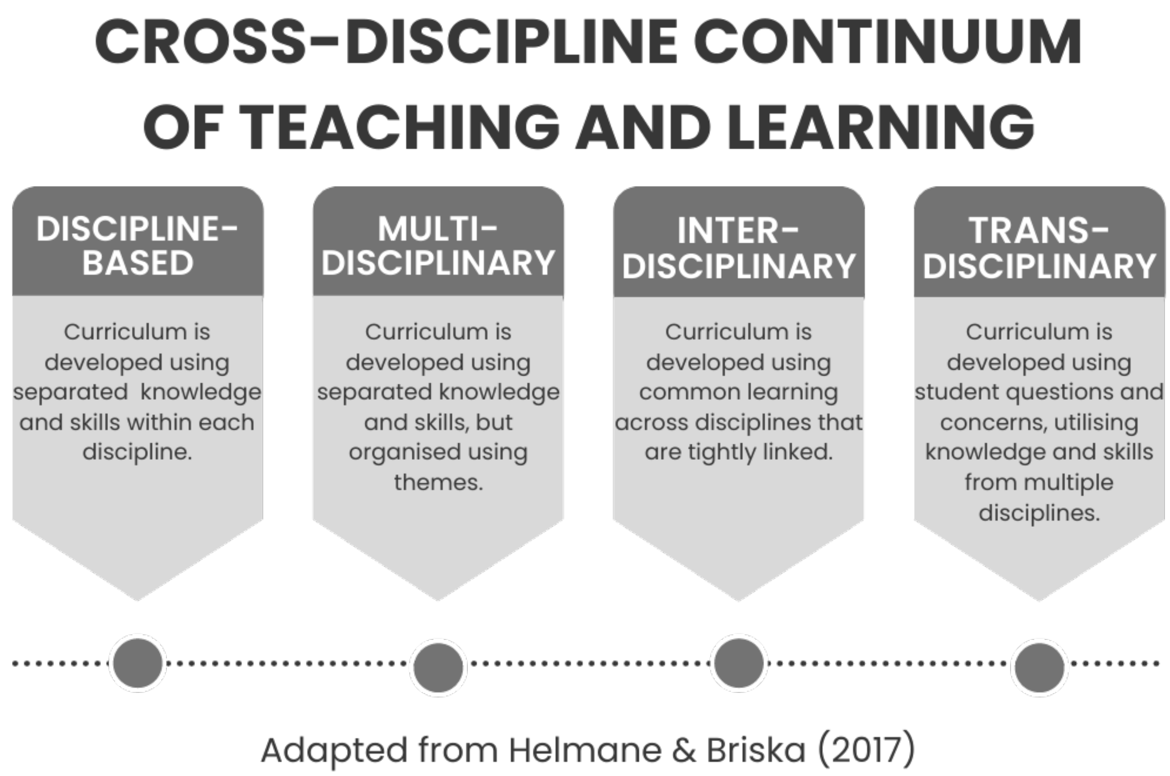
3.0 How is STEM education enacted at Parklands Christian College?

Curriculum enactment, in general, follows the non-integrated philosophies as set up by the curriculum itself. Science curriculum is taught in Science classes, Mathematics is taught in Mathematics classrooms. However as suggested by Kaufman, Moss and Osborne (2003, p. 2) "…the challenge of never being given enough time to do what we would like to do with our students plagues all educators, but none more so than those who view curriculum as something to be covered". They further suggest that moving beyond the coverage-of-curriculum mentality holds the potential for a step towards meaningful educational reform, stating that "progress demands that we view curriculum development from an entirely fresh perspective, one that moves beyond a compilation of information and skills to be methodically delivered to students" (Kaufman, Moss & Osborne, 2003, p. 2). This shift in mindset presents significant challenge, given the socio-historical context of many curricula and the way they have traditionally been enacted in the educational system. Costigan (2003, p. 15) suggests that there are a number of philosophical, cultural and practical boundaries in our educational system that require close examination, and that "crossing these boundaries is an opportunity for an educational conversation that can assist the practice of interdisciplinary teaching and learning" (Costigan, 2003, p. 15). Crossing the boundaries of disciplines, or utilising some kind of "cross-discipline" approach (Costigan, 2003) must be considered as a way forward when enacting emerging STEM curriculum.

Cross-discipline teaching and learning, used here as a broad term encompassing a spectrum of pedagogies, does not have a clear definition in literature but rather fall on a continuum of approaches. Helmane and Briska (2017) conducted a theoretical analysis looking for similarities and differences in the etymology of the terms “multidisciplinary”, “interdisciplinary”, and “transdisciplinary” to create unique definitions for these terms in an educational setting. Figure 1 shows how these terms are being organised within this research project.

Figure 1.

A continuum of cross-discipline approaches to teaching and learning.



Within the Parklands Christian College model of STEM education, a keen focus has been placed on the transdisciplinary end of the continuum, as seems to be the privileged approach in STEM education policy. Many publications use interdisciplinary and transdisciplinary terminology interchangeably, even though it is possible to distinguish clearly between these two terms. The product of Helmane and Briska’s (2017) review suggests that in an interdisciplinary approach, "teachers organise the curriculum around common learning across disciplines" (p. 10). This differentiates from a transdisciplinary approach, where the concepts, research processes and topics converge with significant impact on the perceptions of all sectors involved. Within a transdisciplinary approach, "teachers organise curriculum around student questions and concerns" (Helmane & Briska, 2017, p. 11). This approach clearly sits closer to the priorities of policy surrounding problem-solving and questioning. On a definitive level, transdisciplinary learning is characterised as the exploration of a relevant issue or problem that integrates the perspectives of multiple disciplines in order to connect new knowledge and deeper understanding to real life experiences (Helmane & Briska, 2017). Students experiencing this type of teaching approach are expected to develop key life skills such as teamwork and communication, as they apply interdisciplinary and disciplinary skills in a real-life context. Tasks within this process should be inquiry-based to allow time for discovery, and teachers should organise curriculum around student questions and concerns (Kaufman, Moss, Osborne, 2003). Helmane and Briska (2017, p. 11) argue that there are only two main routes that lead to transdisciplinary integration: project-based learning and negotiating the curriculum. English and King (2015) further illustrate this point by viewing STEM education as far more than a convenient integration, but rather a framework that encompasses authentic problem-solving through cohesive integration of disciplines. The conclusions drawn from this theoretical analysis around the common and distinctive features in these three approaches to integrated teaching and learning are listed clearly, and the Parklands Christian College approach clearly aligns with the transdisciplinary definition.

4.0 Pedagogical philosophy underpinning STEM Studies

With the ultimate goal of leading change in STEM curriculum enactment and equipping students for a multiverse of opportunities, the Parklands Christian College pedagogy emphasises big picture vision, as opposed to simple, non-connected activities. There are five key techniques that are paramount to the STEM Studies classroom:

6. A responsive pedagogy that utilises open-ended questioning techniques to allow for real time flexibility
7. Exposing students to open-ended problem-solving later in the process
8. Promoting and utilising understanding of self, teams and society
9. Framing and tangibly solving problems in authentic contexts

10. Troubleshooting or employing relational strategies to work with students who are disengaged from the process

4.1 Responsive Pedagogy: A responsive pedagogy utilised at Parklands Christian College is defined as the method and practice of responsively teaching students to engage with a new theoretical concept, a new skill, a situation or a problem. Practically speaking, teaching responsively is about getting a feeling for where the group of students are at and adjusting the teaching and learning approach to suit their needs, much like a facilitator of knowledge and skills. This technique can be seen as a back and forth between teachers and students, characterised by an abundance of communication, feedback and short intervals of questioning, to keep the temperature of the room. A teacher spends their time in the room by setting up a scenario, problem or task for students to engage with, then will allow time for students to engage with the STEM process and respond to students' questions, needs or requests for assistance. Some examples from current teacher practice are listed below:

- "I like to think, what are the steps I would go through there, and then try to get them to think about those same sorts of things"
- "let them get off track sometimes as well, because that's a good thing to learn. There is an experience in there as well"

4.2 Using questioning techniques: An important technique that is utilised every lesson is employing a full repertoire of questioning techniques. As teachers, one of the hardest things we can do when a student asks for help is to resist the urge to "do it for them". Imperatively, in STEM Studies, the teacher should view their role as a facilitator of student learning – whether that be passing on specific knowledge, or showing students how to find information Some examples from current teacher practice are listed below:

- "What's it like? Where's everyone at? Are you understanding? Are you on track? Have you deviated by far? Do I need to intervene a bit more, or do I need to give you a little bit more freedom?"

4.3 Exposure to open-ended problem solving: An important component of the STEM Studies program is the opportunity for students to experience open-ended problem solving. Whilst this strategy is scaffolded in Year 9, with specific aspects of the problem-solving process explicitly explained, modelled and practiced; the year 10 program allows students more freedoms in their choice. Key to the Year 10 program is the concept of problem framing – creating a well-defined problem so that solutions often become obvious. This can be a challenging concept for students and teachers alike, as the focus shifts dramatically to baseline assumption of student agency. From a teaching perspective, it can often mean emotionally and practically supporting students through a hard process, that in STEM Studies is referred to as "hitting the wall". It is inevitable that this will happen in every project, where student groups reach a point of not knowing what to do next, or sometimes even not knowing where to start. A teacher should refrain from telling students how to begin or proceed. Teachers should instead use the questioning techniques and refer students back to past experiences to help them move forward. Reaching their challenge point, and continuing to work and make progress, is one of the most valuable learning experiences STEM Studies can offer. Some perspectives from current teacher practice are listed below:

- “By exposing them to these problems and allowing them to come up with their own solutions and… their own problems, we’re changing the way that they think, and then they can apply that across all spectrums. Whether it’s another subject, whether it’s when they go home, out into the community. As you're changing their brain, they take their brain with them everywhere”

4.4 Increasing understandings of self, teams and society: Working effectively towards solutions requires strong understandings of self, teams and society. Students must first understand their own ways of working and nuances, before selecting teams of complementary strengths and weaknesses. Creating diverse groups can be challenging for students, and requires the classroom environment to be transparent and safe for them to take social risks in. Some perspectives from current teacher practice are listed below:

- “…one of the things we did… was expose them to… MBTI. And we talked about working in groups and solving problems in teams. And having those different skills of people that you need to solve problems. That you might need to engage with different people sometimes. We…try and get them to think about… maybe don’t always go with your friends.”

4.5 Working relationally with disengaged students: Some students feel uncomfortable in the STEM Studies classroom as it can be a dramatic shift from the routine and structures they experience in many other secondary classrooms. It is easy for some students to become disengaged from the STEM process, particularly early in the program. It is imperative that teachers watch for these behaviours, and address them quickly. Some strategies from current teacher practice are listed below:

- “I feel that those students, they like structure… we have to change our approach a little bit and just work a lot closer with them. Maybe giving them a little bit more guidance, a little bit more scaffolding, and slowly ease them towards the… open-endedness”
- “… give them a bit of scaffolding around feeling secure so that they think, “Oh, actually I have got a bit of structure, it’s not as bad as I thought.” As they get more and more comfortable, we can take away [the scaffolding].”

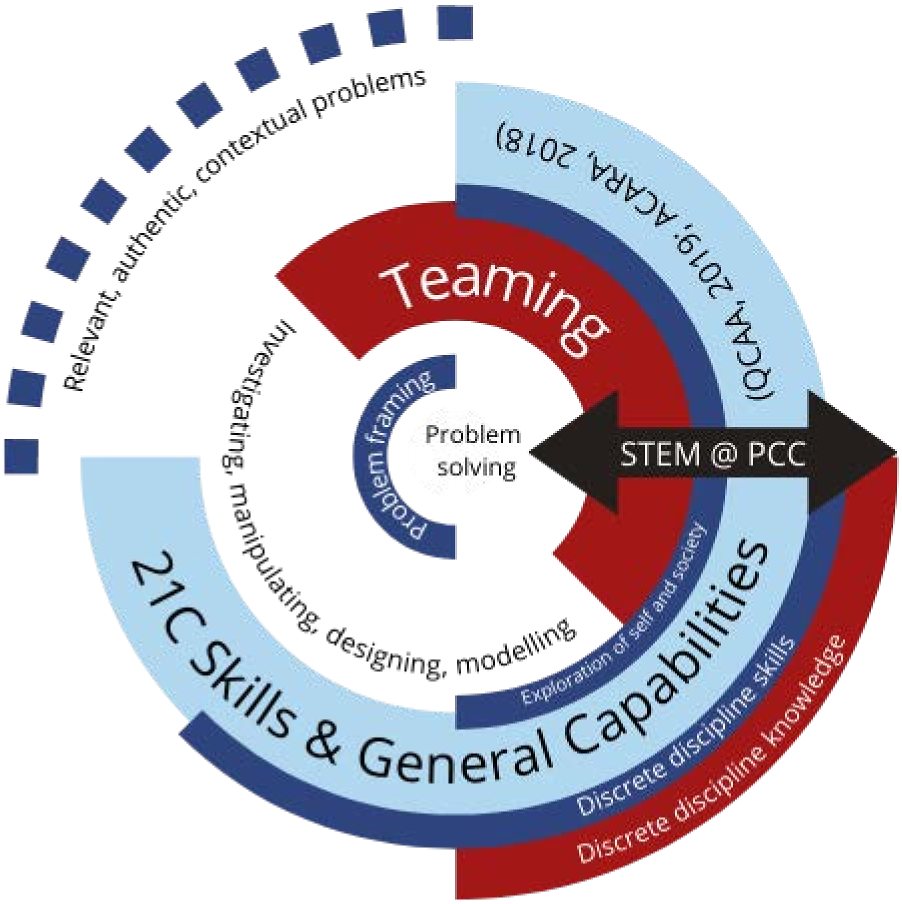


Figure 2. Pedagogical framework for STEM Studies at Parklands Christian College

5.0 Christian Worldview underpinning STEM Studies

5.1 Student agency: 1 Timothy 4:12 "Don't let anyone look down on you because you are young, but set an example for all believers in conduct, in faith, in love, and in purity". Students within a STEM Studies class are viewed as the upcoming generation of Australians, who are learning their place within our society. Their voices are an imperative perspective within the discourse of humanity, and their agency is a highly valued asset that they bring with them into the classroom. The STEM Studies program values their ideas, opinions, worldview and encourages them to pursue their passions in tangible and meaningful ways, rather than limiting them to thought experiments.

5.2 Working together strengthens outcomes: 1 Corinthians 12: 12 "There is one body, but it has many parts. But all its many parts make up one body". Ephesians 4:2-3 "Be completely humble and gentle; be patient, bearing with one another in love. Make every effort to keep the unity of the Spirit through the bond of peace". Students in STEM Studies are encouraged to work together strategically, both within friendship groups and further afield. Whilst this can be a challenging concept for students, it is important that students learn to value the unique perspectives and personalities that each of their fellow students bring as they work together towards a greater goal. Diversity is a fundamental belief that underpins STEM Studies, when many work together it can only strengthen outcomes.

***5.3 Demonstrating love one another*:** John 13:34-35 "A new commandment I give to you: Love one another. As I have loved you, so you must love one another. By this all men will know that you are my disciples, if you love one another". The STEM Studies program at Parklands Christian College encourages students to demonstrate tangible love for fellow humans, both within the course and school environment, and further beyond. Students are always encouraged to pursue projects that provide benefits to others – whether within the school community or at the far reaches of the globe.

6.0 Assessment philosophy

Throughout the implementation journey, a range of assessment strategies were trialled in the STEM studies context. The underpinning philosophy of assessment in STEM is linked clearly to the adopted definition of STEM education, enacted at Parklands. Where the course content and learning experiences should have clear links to authentic, real-world contexts, so should the assessment. Whilst much of the STEM Studies course focusses on effective teaming and working well with others, the summative assessment strategies are designed to be individualistic. There are three key assessment styles used in STEM Studies, detailed in the table below.

Table 1.
Assessment styles used in STEM Studies

Assessment Type	Details	Timing
Student interviews	• Individual task • **Summative task** • Pre-interview, students complete a self-evaluation tool, that includes a rubric to mark • One-to-one interview with a teacher, where students provide evidence of how they self-evaluated • Student and teacher negotiate a grade for the students' in-class performance for the term	Occur in exam blocks
Student conferences	• Group task • **Formative task** • Students prepare a presentation of their progress • Students present the presentation to the class • The class provides formal feedback by way of feedback form • Teacher compiles feedback per group, and then releases it back to the group	Occur mid-term, to allow students to implement the feedback they are given
Project evaluations	• Individual task • **Summative task** • Written task • Formal, evaluative report • Recommended 600-800 words in Year 9 • Recommended 800-1000 words in Year 10	Occurs at the end of term, usually after student interviews

6.1 Student interviews: Student interviews mimic the structures of employment based performance review meetings. Students should complete a self-evaluation tool before they attend their interview, where they rate their performance in class. Students should then come prepared to the interview, with evidence of how they have self-assessed. Self-assessment is an important part of authentic assessment, as described by Scott (2000, p. 34) who states that “A key aspect of many forms of authentic assessment is the opportunities that are provided for students to reflect on their thinking, practices, and learning”.

6.2 Student conferences: Student conferences are designed as a feedback gathering process, and should be viewed as a formative assessment item. Student conferences are designed to develop a range of skills in students, including presentation and public speaking skills, critical analysis of ideas, providing helpful feedback, accepting and implementing feedback as a part of iterative designing. Before student conferences are first implemented in Year 9, there is explicit teaching around the purpose and format of student conferences, as well as how to provide helpful, critical feedback. In Year 9, the feedback gathering process has more structures in place, for example teacher created feedback forms, to ensure students develop these skills in effective and helpful ways, reducing the possibility for negative and overly harsh feedback being provided on ideas.

6.3 Project evaluations: Project evaluations are a formal, written document that is produced by individual students. The Year 9 project evaluations are highly structured as students are scaffolded towards effective oral and written communication, and the ability to communicate ideas effectively with diverse audiences.

7.0 Course Overview

7.1 STEM Studies course map

The STEM Studies course at Parklands Christian College is designed to be a two-year learning journey that culminates in a major project in Semester 2 of Year 10. Through Year 9, there are more structures in place as the students are scaffolded towards independent project work, using a gradual release of responsibility pedagogy (Killian, 2015). Learning experiences focus on building a repertoire of thinking skills, project management strategies and communication skills. Then in Year 10, students experience more freedom to explore their interests and passions, with a focus on problem framing and then problem solving skills, as well as supporting students to move beyond the theoretical, towards the practical.

Table 2.
Course Overview

<table>
<tr><th></th><th>Year 9</th><th>Year 10</th></tr>
<tr><td>Yearly focus</td><td>I DO to WE DO (Killian, 2015)
Experiences that build:
- Thinking skills
- Interpersonal skills
- Project management skills
- Communication skills</td><td>WE DO to YOU DO (Killian, 2015)
Experiences that build:
- Problem framing skills
- Problem solving skills
- Moving from ideation to implementation</td></tr>
<tr><td>Term 1</td><td>Focus: Understanding STEM @ PCC and unlearning habits
Explicit teaching of:
- The STEM process
- Understanding of self and society
- Teaming
- Unlearning how to do school
Project: Turtlegate Mythology
Assessment: Student interview and project evaluation</td><td>Focus: Framing problems so solutions are easy
Explicit teaching of:
- Problem definitions
- Problem niches
- Solutions that suit the circumstances
Project: The Two Week Project
Assessment: Student conferences and student interviews</td></tr>
<tr><td>Term 2</td><td>Focus: Gaining and using feedback
Explicit teaching of:
- Seeking useful feedback
- Using feedback to iterate
- Student conferences
Project: School based project (litter or wet kids in the rain)
Assessment: Student conferences and project evaluation</td><td>Focus: Critical and creative thinking
Explicit teaching of:
- Idea generation
- Iterative design
- Critical thinking process
Project: Student choice project
Assessment: Student interviews and project evaluation</td></tr>
<tr><td>Term 3</td><td>Focus: Collecting and using good data
Explicit teaching of:
- Strategising
- Collecting good data
- Interpreting and using data to refine a project
Project: The Teacher Project
Assessment: Student conferences and student interviews</td><td rowspan="2">Focus: Using the STEM process to ideate and implement solutions
Explicit teaching of:
- Self-education and seeking help
Project: Student choice project
Assessment:
- Term 3: Student conferences and student interviews
- Term 4: Project evaluation and student interviews</td></tr>
<tr><td>Term 4</td><td>Focus: Using time and resources well
Explicit teaching of:
- Time management
- Leadership and delegation
- Roles in teams</td></tr>
</table>

	Project: Student choice project **Assessment:** Student conferences and student interviews	

7.2 Skills focus: The Queensland Curriculum & Assessment Authority [QCAA] have produced a position paper on the essential nature of the 21st century skills. Their position paper directly relates to the development of the skills for students to be successful within the senior system, and then beyond as they move into a rapidly changing world.

> *"The Queensland Curriculum and Assessment Authority (QCAA) has identified and defined a set of 21st century skills based on national and international research about the skills students need in the 21st century. Along with literacy and numeracy, these 21st century skills are the underpinning factors that shape the development of the General senior syllabuses. These 21st century skills will help prepare Queensland students by giving them the knowledge, skills and confidence they need to be equipped for the demands of higher education, work and life, and to participate effectively in the community and the economy in a complex and rapidly changing world."* (QCAA, 2017, p. 1).

Figure 2.

QCAA defined 21st century skills

21st century skills

21st century skills and associated skills

21st century skills	Associated skills	21st century skills	Associated skills
critical thinking	• analytical thinking • problem-solving • decision-making • reasoning • reflecting and evaluating • intellectual flexibility	creative thinking	• innovation • initiative and enterprise • curiosity and imagination • creativity • generating and applying new ideas • identifying alternatives • seeing or making new links
communication	• effective oral and written communication • using language, symbols and texts • communicating ideas effectively with diverse audiences	collaboration and teamwork	• relating to others (interacting with others) • recognising and using diverse perspectives • participating and contributing • community connections
personal and social skills	• adaptability/flexibility • management (self, career, time, planning and organising) • character (resilience, mindfulness, open- and fair-mindedness, self-awareness) • leadership • citizenship • cultural awareness • ethical (and moral) understanding	information & communication technologies (ICT) skills	• operations and concepts • accessing and analysing information • being productive users of technology • digital citizenship (being safe, positive and responsible online)

The 21st century skills (QCAA, 2019) form the foundation of the STEM Studies course, as teachers endeavour to:

- model the 21st century skills
- explicitly teach and provide examples of the 21st century skills in action
- provide a variety of learning activities that support the development of the 21st century skills
- provide opportunities for students to practise the 21st century skills as authentic elements of the subject
- provide feedback to students on the 21st century skills

9 STEM Studies Profile

Student name:

Self-reflection tasks:

Self-reflection tasks are completed by students at the end of each term. Students allocate a grade for themselves, and then provide justification in the form of reflective writing and a portfolio of evidence. Students then meet with their teacher individually and agree on an overall grade for their performance across the term after reviewing the reflective writing and portfolio of evidence.

	Term 1		Term 2		Term 3		Term 4	
Criteria	**Self Grade**	**Reflection & justification**	**Self Grade**	**Reflection & justification**	**Self Grade**	**Reflection & justification**	**Self Grade**	**Reflection & justification**
Thinking Skills								
Critical thinking								
Creative thinking								
Interpersonal Skills								
Personal & social skills								
Collaboration & teamwork								
Communication								
Use of technology								
ICT Skills								
Overall Grade:		**Agreed Grade:** A / B / C / D / E		**Agreed Grade:** A / B / C / D / E		**Agreed Grade:** A / B / C / D / E		**Agreed Grade:** A / B / C / D / E

Project evaluation tasks:

Project evaluation tasks are completed by students at the end of each major project. Students are marked according to the STEM Studies criteria.

	Term 1: Project evaluation	Term 2: Project evaluation	Term 4: Project evaluation
Criteria	**Grade**	**Grade**	**Grade**
Thinking skills			
Critical thinking			
Creative thinking			
Interpersonal skills			
Personal & social skills			
Collaboration & teamwork			
Communication			
Use of technology			
ICT Skills			
Overall Grade:	**A / B / C / D / E**	**A / B / C / D / E**	**A / B / C / D / E**

Overall level of achievement:

Project evaluation tasks are completed by students at the end of each major project. Students are marked according to the STEM Studies criteria.

	Term 1	**Term 2**	**Term 3**	**Term 4**
	Grade	**Grade**	**Grade**	**Grade**
Student conference (formative)		Completed / Not Completed	Completed / Not Completed	Completed / Not Completed
Self-reflection agreed grade (summative)				
Project evaluation (summative)				
Overall Term Grade:	**A / B / C / D / E**	**A / B / C / D / E**	**A / B / C / D / E**	**A / B / C / D / E**
Overall Semester LOA:	**A / B / C / D / E**		**A / B / C / D / E**	

		A	B	C	D	E
Thinking Skills	Critical Thinking	**Thorough** and/or **justified** explanation of **most** of the following: - Analytical thinking - Problem-solving process - Decision making process - Reasoning - Reflecting and evaluations - Intellectual flexibility	**Informed** explanation of **most** of the following: - Analytical thinking - Problem-solving process - Decision making process - Reasoning - Reflections and evaluations - Intellectual flexibility	**Explanation** of **most** of the following: - Analytical thinking - Problem-solving process - Decision making process - Reasoning - Reflecting and evaluating - Intellectual flexibility	**Description** of **some** of the following: - Thinking - Problem-solving process - Decision making process - Reasoning - Reflections - Intellectual flexibility	**Statements** about **some** of the following: - Thinking - Problem-solving process - Decision making process - Reasoning - Reflections - Intellectual flexibility
	Creative Thinking	**Thorough** and/or **justified** explanation of **most** of the following: - Innovation - Initiative - Generating and applying new ideas - Identifying alternatives - Seeing or making new links	**Informed** explanation of **most** of the following: - Innovation - Initiative - Generating and applying new ideas - Identifying alternatives - Seeing or making new links	**Explanation** of **most** of the following: - Innovation - Initiative - Generating and applying new ideas - Identifying alternatives - Seeing or making new links	**Description** of **some** of the following: - Innovation - Initiative - Generating and applying new ideas - Identifying alternatives - Seeing or making new links	**Statements** about **some** of the following: - Innovation - Initiative - Generating and applying new ideas - Identifying alternatives - Seeing or making new links
Interpersonal skills	Personal and social skills	**Thorough** and/or **justified** explanation of **most** of the following: - Flexibility	**Informed** explanation of **most** of the following: - Flexibility	**Explanation** of **most** of the following: - Flexibility - Time management	**Description** of **some** of the following: - Flexibility - Time management	**Statements** about **some** of the following: - Flexibility - Time management

		- Time management - Leadership - Citizenship - Cultural awareness - Ethical understanding	- Time management - Leadership - Citizenship - Cultural awareness - Ethical understanding	- Leadership - Citizenship - Cultural awareness - Ethical understanding	- Leadership - Citizenship - Cultural awareness - Ethical understanding	- Leadership - Citizenship - Cultural awareness - Ethical understanding
	Collaboration and teamwork	**Thorough** and/or **justified** explanation of **most** of the following: - Recognising and using diverse perspectives - Participating and contributing - Community connections	**Informed** explanation of **most** of the following: - Recognising and using diverse perspectives - Participating and contributing - Community connections	**Explanation** of **most** of the following: - Recognising and using diverse perspectives - Participating and contributing - Community connections	**Description** of **some** of the following: - Recognising and using diverse perspectives - Participating and contributing - Community connections	**Statements** about **some** of the following: - Recognising and using diverse perspectives - Participating and contributing - Community connections
	Communication	**Concise** and **coherent:** - Oral and written communication skills - Use of language, symbols and texts - Communication of ideas effectively with diverse audiences	**Accurate** and **appropriate**: - Oral and written communication skills - Use of language, symbols and texts - Communication of ideas effectively with diverse audiences	**Use** of **appropriate**: - Oral and written communication skills - Use of language, symbols and texts - Communication of ideas effectively with diverse audiences	Use of **everyday language** and representations when communicating findings to audiences.	**Fragmented** use of language and representations when communicating findings to audiences.

Use of technology	ICT Skills	**Discerning** use of: - Operations and concepts - Access for information - Information analysis - Fit for purpose technology	**Effective** use of: - Operations and concepts - Access for information - Information analysis - Fit for purpose technology	**Appropriate** use of: - Operations and concepts - Access for information - Information analysis - Fit for purpose technology	**Some** use of: - Operations and concepts - Access for information - Information analysis - Fit for purpose technology	**Little** use of: - Operations and concepts - Access for information - Information analysis - Fit for purpose technology

10 STEM Studies Profile

Student name:

Self-reflection tasks:

Self-reflection tasks are completed by students at the end of each term. Students allocate a grade for themselves, and then provide justification in the form of reflective writing and a portfolio of evidence. Students then meet with their teacher individually and agree on an overall grade for their performance across the term after reviewing the reflective writing and portfolio of evidence.

	Term 1		Term 2		Term 3		Term 4	
Criteria	**Self Grade**	**Reflection & justification**	**Self Grade**	**Reflection & justification**	**Self Grade**	**Reflection & justification**	**Self Grade**	**Reflection & justification**
Thinking Skills								
Critical thinking								
Creative thinking								
Interpersonal Skills								
Personal & social skills								
Collaboration & teamwork								
Communication								
Use of technology								
ICT Skills								
Overall Grade:		**Agreed Grade:**		**Agreed Grade:**		**Agreed Grade:**		**Agreed Grade:**

		A / B / C / D / E		**A / B / C / D / E**		**A / B / C / D / E**		**A / B / C / D / E**

Project evaluation tasks:

Project evaluation tasks are completed by students at the end of each major project. Students are marked according to the STEM Studies criteria.

	Term 2: Project evaluation	**Term 3: Mid-Project evaluation**	**Term 4: Project evaluation**
Criteria	**Grade**	**Grade**	**Grade**
Thinking skills			
Critical thinking			
Creative thinking			
Interpersonal skills			
Personal & social skills			
Collaboration & teamwork			
Communication			
Use of technology			
ICT Skills			
Overall Grade:	**A / B / C / D / E**	**A / B / C / D / E**	**A / B / C / D / E**

Overall level of achievement:

Project evaluation tasks are completed by students at the end of each major project. Students are marked according to the STEM Studies criteria.

	Term 1	**Term 2**	**Term 3**	**Term 4**
	Grade	**Grade**	**Grade**	**Grade**
Student conference (formative)	Completed / Not Completed		Completed / Not Completed	Completed / Not Completed
Self-reflection agreed grade (summative)				
Project evaluation (summative)				
Overall Term Grade:	**A / B / C / D / E**	**A / B / C / D / E**	**A / B / C / D / E**	**A / B / C / D / E**
Overall Semester LOA:	**A / B / C / D / E**		**A / B / C / D / E**	

		A	B	C	D	E
Thinking Skills	Critical Thinking	**Thorough** and/or **justified** explanation of **most** of the following: - Analytical thinking - Problem-solving process - Decision making process - Reasoning - Reflecting and evaluations - Intellectual flexibility	**Informed** explanation of **most** of the following: - Analytical thinking - Problem-solving process - Decision making process - Reasoning - Reflections and evaluations - Intellectual flexibility	**Explanation** of **most** of the following: - Analytical thinking - Problem-solving process - Decision making process - Reasoning - Reflecting and evaluating - Intellectual flexibility	**Description** of **some** of the following: - Thinking - Problem-solving process - Decision making process - Reasoning - Reflections - Intellectual flexibility	**Statements** about **some** of the following: - Thinking - Problem-solving process - Decision making process - Reasoning - Reflections - Intellectual flexibility
	Creative Thinking	**Thorough** and/or **justified** explanation of **most** of the following: - Innovation - Initiative - Generating and applying new ideas - Identifying alternatives - Seeing or making new links	**Informed** explanation of **most** of the following: - Innovation - Initiative - Generating and applying new ideas - Identifying alternatives - Seeing or making new links	**Explanation** of **most** of the following: - Innovation - Initiative - Generating and applying new ideas - Identifying alternatives - Seeing or making new links	**Description** of **some** of the following: - Innovation - Initiative - Generating and applying new ideas - Identifying alternatives - Seeing or making new links	**Statements** about **some** of the following: - Innovation - Initiative - Generating and applying new ideas - Identifying alternatives - Seeing or making new links
Interpersonal skills	Personal and social skills	**Thorough** and/or **justified** explanation of **most** of the following: - Flexibility	**Informed** explanation of **most** of the following: - Flexibility	**Explanation** of **most** of the following: - Flexibility	**Description** of **some** of the following: - Flexibility	**Statements** about **some** of the following: - Flexibility

		- Time management - Leadership - Citizenship - Cultural awareness - Ethical understanding	- Time management - Leadership - Citizenship - Cultural awareness - Ethical understanding	- Time management - Leadership - Citizenship - Cultural awareness - Ethical understanding	- Time management - Leadership - Citizenship - Cultural awareness - Ethical understanding	- Time management - Leadership - Citizenship - Cultural awareness - Ethical understanding
	Collaboration and teamwork	**Thorough** and/or **justified** explanation of **most** of the following: - Recognising and using diverse perspectives - Participating and contributing - Community connections	**Informed** explanation of **most** of the following: - Recognising and using diverse perspectives - Participating and contributing - Community connections	**Explanation** of **most** of the following: - Recognising and using diverse perspectives - Participating and contributing - Community connections	**Description** of **some** of the following: - Recognising and using diverse perspectives - Participating and contributing - Community connections	**Statements** about **some** of the following: - Recognising and using diverse perspectives - Participating and contributing - Community connections
	Communication	**Concise** and **coherent:** - Oral and written communication skills - Use of language, symbols and texts - Communication of ideas effectively with diverse audiences	**Accurate** and **appropriate**: - Oral and written communication skills - Use of language, symbols and texts - Communication of ideas effectively with diverse audiences	**Use** of **appropriate**: - Oral and written communication skills - Use of language, symbols and texts - Communication of ideas effectively with diverse audiences	Use of **everyday language** and representations when communicating findings to audiences.	**Fragmented** use of language and representations when communicating findings to audiences.

Use of technology	ICT Skills	**Discerning** use of: - Operations and concepts - Access for information - Information analysis - Fit for purpose technology	**Effective** use of: - Operations and concepts - Access for information - Information analysis - Fit for purpose technology	**Appropriate** use of: - Operations and concepts - Access for information - Information analysis - Fit for purpose technology	**Some** use of: - Operations and concepts - Access for information - Information analysis - Fit for purpose technology	**Little** use of: - Operations and concepts - Access for information - Information analysis - Fit for purpose technology

Appendix 9 – Sample assessment instrument

10 STEM

Task 4: Project Evaluation

Student name:	
Class:	10 STEM
Teacher:	Mrs Schulz
Issue Date:	Term 3: Week 1
Draft Due Date:	Term 3, Week 8: During student interview
Final Due Date:	Term 4, Week 6

Criterion			Grade	Overall Grade
Thinking Skills				
Interpersonal Skills				
ICT Skills				

Conditions:	
Unit	Term 3-4 “The Big Boppa”
Mode	Written
Duration	2 terms to complete, with 10 in class lessons to complete

Length	1000 words – see task description for more information
Individual/group	Individual
Resources available	https://sites.google.com/parklands.qld.edu.au/stemstudies/home

Context
Throughout Term 3-4, students have focussed on idea generation strategies, iterative design and moving from theory to action. Students have engaged in a student choice project, with a focus on authentic problem-solving and an urgency around getting a project finished and evaluated. Students were asked to consider the scope and scale of their project, to ensure it can be completely finished within the two terms.

Task

The aim of this task is to evaluate your group's implemented project, and your personal performance this term. You need to write an evaluative report, using the following headings as a guide for what to write. If there is information that you would like your teacher to know, that isn't included under one of these headings, you may add an extra section.

To complete the evaluation task, your written submission must contain:

The word limit for this task is 1000 words. If you need more words to fully communicate your evaluation of the project, you are welcome to alter the word limit. Just keep the marking rubric in mind – the A standard column uses the terminology that your explanations must be "thorough and/or justified". Thorough means "complete with regard to every detail; not superficial or partial". Justified means "to prove with evidence".

Use the following subsections to structure your evaluative report:

1. **Introduction / Description of project**
    - Introduction to provide an overview of your completed project
    - Clearly define the problem that your team is addressing

- Describe the solution your team implemented
- Describe your success criteria for the project

2. Thinking Skills – reflect on your personal performance this term

- Explain and justify your critical thinking skills
  - Explain the problem-solving process that you undertook
  - Explain how you were flexible in adapting to the constraints around the project (e.g. the limited amount of time, limited resources, approval processes).
- Explain and justify your creative thinking skills
  - Explain how your project design was innovative
  - Explain how you came up with the idea for your creation
  - Explain your background research. What did it tell you?

3. Interpersonal Skills – reflect on your personal performance this term

- Reflect on and explain how personal and social skills helped you in this project
  - Reflect on your time management
  - Explain how you considered the ethical implications of your project (for example, how you were inclusive / sensitive to other cultures and people, the environment, etc).
- Reflect on and explain how collaboration and teamwork helped you in this project
  - Explain how you incorporated different ideas from people within the group
  - Reflect on your personal participation and contributions to the project
- Reflect on and explain your communication within this project
  - Reflect on how you communicated your ideas to your group

4. Evaluation

- Evaluate the relative success of your project and reflect on what else could have been done

- Did you meet the success criteria? Why / why not?

5. **Conclusion**

- Write a conclusion that summarises your key learnings from this term
- If possible, make recommendations for future research or actions.

Checkpoints for project evaluation
• **Handed out – Term 3** Hand out and discuss task Students complete the graphic organiser • **Submit weekly reviews – Term 3 and Term 4** Students begin task • **Student interview draft – Term 3, Week 9 and Term 4, Week 6** Students continue task • **Submit final – Term 4, Week 9** Students complete task and final is submitted
Authentication strategies Your teacher will use ways to check that the work you are assessed on is your own work.
• Weekly reviews submitted through Google Classroom
• Final evaluation submitted through Google Classroom
• Verbal draft feedback during student interview

BIG BOPPA PROJECT OVERVIEW & PLANNING:

Dear Young Australian,

You are the future. But… you are also the present. Too often, social sentiments of youth stop at the end of that first sentence. Of course, it is completely true – you are the future, you have lots of time ahead of you, but you are also the present. You have a voice, and a strong sense of agency right now. You have a unique and important perspective of the world. You have a different socialization to those older than you. You are digital natives with the tools to mobilise and speak out, to find information, to raise awareness, to create, multi-task and sustain. *Your unique perspective is a testament to the energy of youth.*

You have been privileged to experience at least some of your formative years, if not all of them, in a unique and amazing country. You come from a country of creative thinkers, of designers, of hard workers, of larrikins and questioners, of brave and courageous people. Australians aren't afraid to do things differently. We are world renown as the moral and ethical questioners – we always ask the WHY questions. *Your unique perspective is a testament to the value Australia holds for humanity and our amazing creativity*.

The next 6 months of your STEM course won't be easy. You will feel frustrated and challenged as you work out who you are in this space. Your knowledge and understanding of the world will be stretched as you work hard to function harmoniously as a group. Don't give up when you feel frustrated, but rather look at this as a privileged opportunity to grow in your understanding of the human condition. *Your unique perspective of the world is about to be increased by a significant challenge.*

Your task is to use your perspective, agency and tools to tackle one of the following gnarly, wicked problems that are currently facing the human race. And not in a school assignment, kinda half think about it way, but in a REAL way. You really have to brainstorm a solution. You really have to design and map your solution. You really have to prototype, test and refine your solution based on data. You really have to produce a final solution that you can gift to the world as an offering of your perspective.

We ask you to do these things not because they are fun or silly or just for a grade on a school assignment. We ask you to look closely and bring your perspective to these problems because they are important for all of our futures. When we look at our children and grandchildren, we want to leave a world for them and future generations that is harmonious and sustainable. Your task is to give these problems a red-hot Aussie crack.

Looking forward in anticipation to the brilliance of your solutions,

The human race xx

1 Timothy 4:12

Don't let anyone look down on you because you are young, but set an example for everyone in speech, in conduct, in love, in faith and in purity.

Choose one of the following challenges as the context for your project:

Challenge	Description	Success criteria
Digital Learning Challenge (X-Prize, 2021)	The needs to students, from early years to higher education, are evolving every day. With the power of digital learning tools, increasing connectivity, acceleration in Big Data, machine learning and AI methods, technology provides an opportunity to measure, improve learning and our understanding of how learning takes place. While many learning platforms already collect data and conduct substantive analyses, practices to collect data with the intention of understanding learning rather than for technical debugging are not widespread.	Build a system that conducts rapid, reproducible experiments to tests the resilience and rigour of learning methods. Test a range of learning platforms that have been used in your schooling and decide if they were effective learning tools or not.
Next-gen Mask Challenge (X-Prize, 2021)	Masks are effective in slowing and preventing the spread of COVID-19, but not all of us have adopted this preventative measure. Some masks are ill-fitting, uncomfortable, not breathable and most effective masks are unavailable or expensive. We need an alternative – face masks that are readily accessible and affordable, functional for our everyday lives, fit a wide variety of wearers, and are effective in	Design a face masks that achieves the filtration efficacy on par with a surgical mask and overcomes the top five barriers to mask-wearing as defined in the challenge.

	protecting the wearer and the community.	
Rainforest Challenge: Discover, Understand, Preserve (X-Prize, 2021)	Rainforests cover less than 10% of the earth's land surface, but they house approximately 50 million inhabitants and over 50% of the planet's biodiversity. Although they are the most biodiverse ecosystems, there is a limited knowledge of everything that lives in these iconic environments. The value of the standing trees are not fully understood and our ability to assess this value is restricted because the rainforest environment is dense, vast and complex.	Develop a novel technology to rapidly and comprehensively survey rainforest biodiversity and use that data to improve our understanding of this complex ecosystem.
Anywhere is Possible Challenge (X-Prize, 2021)	There is potential for avatars to take on many different forms and be used in numerous scenarios. For example, <u>Providing Care</u> *Avatars could give the experience of your presence and care to anyone instantly, regardless of distance.* <u>Disaster Relief</u> *Avatars could transport critical life-saving skills in real-time to remote, disaster struck areas where it is too dangerous for humans to go.* <u>Education</u> *Students can experience far flung locations, cultures and people in a time of global pandemic and reduced travel*	Integrate multiple emerging technologies to develop a physical, non-autonomous Avatar System with which an operator can see, hear and interact within a remote environment in a manner that feels as if they are truly there.

Future Education Challenge (X-Prize, 2021)	As the human race grapples with a rapidly changing world, many facets of life that have existed peacefully are being called into question. Jobs, workspaces and basic understandings of the world are rarely divided into silos of knowledge anymore: Biologists have become Biotech engineers, Big Data rules our access to news and information, jobs are replaced by automated procedures. The school environment is a young person's first venture into the workspaces of the world, yet the model still privileges industrial revolution thinking.	Build a conceptual framework for the future of education, that prepares students for an uncertain future. Test your framework for feasibility in the areas of: - Learning - Preparation for future - Enjoyment - Teacher role
Student Choice Challenge	A suitable, contextual challenge can be negotiated with your teacher. Record your challenge here:	A suitable, contextual set of success criteria must be established before the project can be approved to launch. Record your success criteria here:

Group Members:	
Challenge:	

Term 3	Tasks
Week 1	Assignment Released Team building Checkpoint: Team Dynamics
Weeks 2-5	Project work as identified by group Checkpoint: Ideation Checkpoint: Planning and Timelines
Weeks 6- 9	Project work as identified by group Student conferences – present your project to the group for feedback Checkpoint: Data Collection Checkpoint: Feedback Integration
Week 10	Mid-Semester evaluation checkpoint due Checkpoint: Term 4 Plan
Term 4	**Tasks**
Weeks 1 - 6	Project work as identified by group Checkpoint: Endgame Plan
Week 7	Project work as identified by group Student conferences – present your project to the group for feedback Checkpoint: Evaluation Draft
Week 8	Final project evaluation due Checkpoint: Reflections on STEM

Checkpoint 1: Team Dynamics

1. Outline below your role within the team. Include in your answer the reason why you selected this role within the team, and how you plan to contribute.

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2. Briefly describe the team dynamics at this early stage of your project. What challenges do you anticipate you will face as a team? What are some strategies you can use when faced with challenging team dynamics?

3. What parts of the project will be everyone's responsibility? How will you contribute beyond your defined role?

Checkpoint 2: Ideation

Use the space below during the ideation phase.

Checkpoint 3: Planning and Timelines

Use the below space to draw a timeline of your group's project to completion. Update the timeline when it changes. Make it messy!

Checkpoint 4: Data collection

Use the space below to record data you have collected. Link to appendices if more space is needed.

Checkpoint 5: Feedback integration

Record key feedback points provided by other groups at your student conference.

Feedback can be “key” if it is interesting, useful, thought-provoking or critical!

How can you integrate this feedback into your prototype?

Checkpoint 6: Term 4 Plan

Before going on holidays, make a solid plan for Term 4. Include specific jobs that need finishing, loose ends that need tying up and big picture ideas.

Checkpoint 7: Endgame plan

We're in the endgame now! Making solid plans and sticking to timelines are even more important now! So what's the plan? Outline it below, and update it as it evolves.

		A	B	C	D	E
Thinking Skills	Critical Thinking	**Thorough** and/or **justified** explanation of **most** of the following: - Analytical thinking - Problem-solving process - Decision making process - Reasoning - Reflecting and evaluations - Intellectual flexibility	**Informed** explanation of **most** of the following: - Analytical thinking - Problem-solving process - Decision making process - Reasoning - Reflections and evaluations - Intellectual flexibility	**Explanation** of **most** of the following: - Analytical thinking - Problem-solving process - Decision making process - Reasoning - Reflecting and evaluating - Intellectual flexibility	**Description** of **some** of the following: - Thinking - Problem-solving process - Decision making process - Reasoning - Reflections - Intellectual flexibility	**Statements** about **some** of the following: - Thinking - Problem-solving process - Decision making process - Reasoning - Reflections - Intellectual flexibility
	Creative Thinking	**Thorough** and/or **justified** explanation of **most** of the following: - Innovation - Initiative - Generating and applying new ideas - Identifying alternatives - Seeing or making new links	**Informed** explanation of **most** of the following: - Innovation - Initiative - Generating and applying new ideas - Identifying alternatives - Seeing or making new links	**Explanation** of **most** of the following: - Innovation - Initiative - Generating and applying new ideas - Identifying alternatives - Seeing or making new links	**Description** of **some** of the following: - Innovation - Initiative - Generating and applying new ideas - Identifying alternatives - Seeing or making new links	**Statements** about **some** of the following: - Innovation - Initiative - Generating and applying new ideas - Identifying alternatives - Seeing or making new links

Interpersonal skills	Personal and social skills	**Thorough** and/or **justified** explanation of **most** of the following: - Flexibility - Time management - Leadership - Citizenship - Cultural awareness - Ethical understanding	**Informed** explanation of **most** of the following: - Flexibility - Time management - Leadership - Citizenship - Cultural awareness - Ethical understanding	**Explanation** of **most** of the following: - Flexibility - Time management - Leadership - Citizenship - Cultural awareness - Ethical understanding	**Description** of **some** of the following: - Flexibility - Time management - Leadership - Citizenship - Cultural awareness - Ethical understanding	**Statements** about **some** of the following: - Flexibility - Time management - Leadership - Citizenship - Cultural awareness - Ethical understanding
	Collaboration and teamwork	**Thorough** and/or **justified** explanation of **most** of the following: - Recognising and using diverse perspectives - Participating and contributing - Community connections	**Informed** explanation of **most** of the following: - Recognising and using diverse perspectives - Participating and contributing - Community connections	**Explanation** of **most** of the following: - Recognising and using diverse perspectives - Participating and contributing - Community connections	**Description** of **some** of the following: - Recognising and using diverse perspectives - Participating and contributing - Community connections	**Statements** about **some** of the following: - Recognising and using diverse perspectives - Participating and contributing - Community connections
	Communication	**Concise** and **coherent:** - Oral and written communication skills - Use of language, symbols and texts	**Accurate** and **appropriate**: - Oral and written communication skills - Use of language, symbols and texts	**Use** of **appropriate**: - Oral and written communication skills - Use of language, symbols and texts	Use of **everyday language** and representations when communicating findings to audiences.	**Fragmented** use of language and representations when communicating findings to audiences.

		- Communication of ideas effectively with diverse audiences	- Communication of ideas effectively with diverse audiences	- Communication of ideas effectively with diverse audiences		
Use of technology	ICT Skills	**Discerning** use of: - Operations and concepts - Access for information - Information analysis - Fit for purpose technology	**Effective** use of: - Operations and concepts - Access for information - Information analysis - Fit for purpose technology	**Appropriate** use of: - Operations and concepts - Access for information - Information analysis - Fit for purpose technology	**Some** use of: - Operations and concepts - Access for information - Information analysis - Fit for purpose technology	**Little** use of: - Operations and concepts - Access for information - Information analysis - Fit for purpose technology

Overall Grade

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